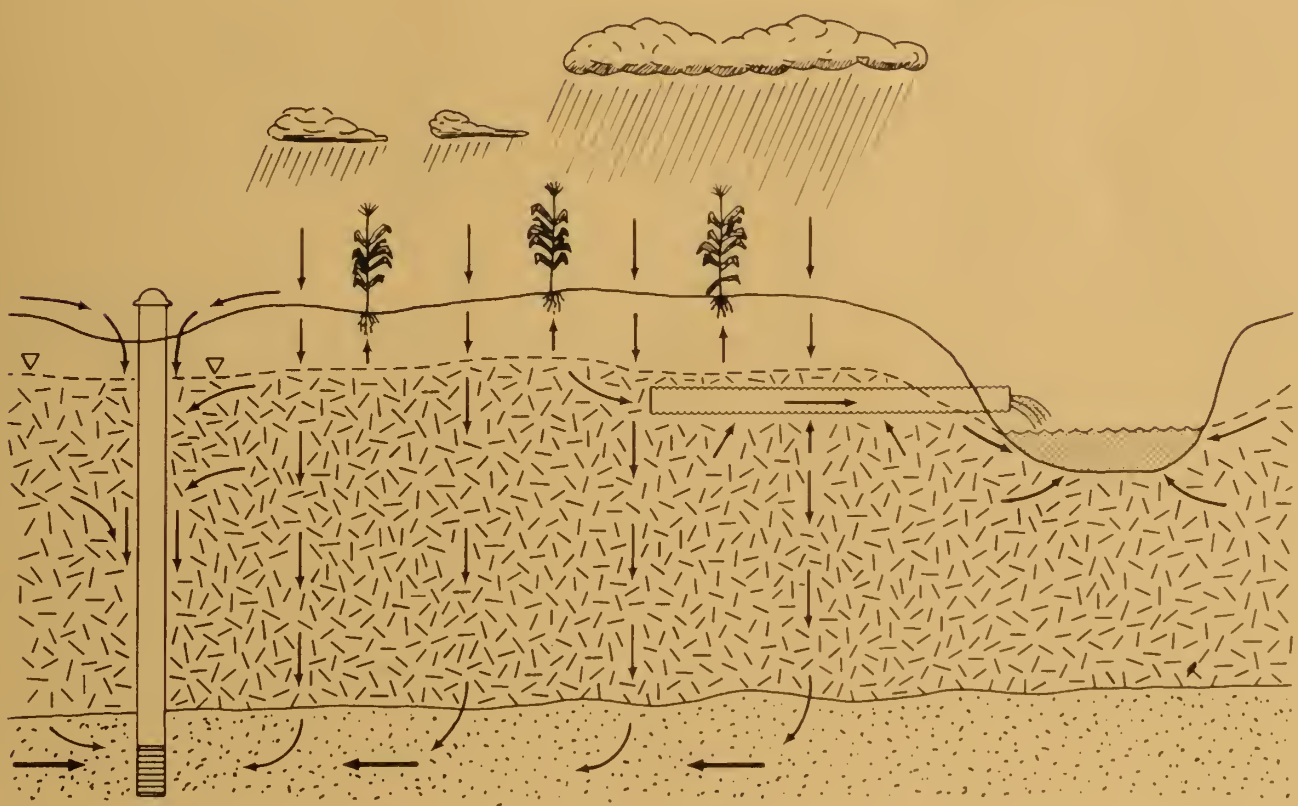
Potential for Agricultural Chemical Contamination of Aquifers in Illinois: 1995 Revision

Donald A. Keefer



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INTRODUCTION

Predicting groundwater vulnerability to contamination by agricultural chemicals is one of the most pressing environmental issues facing farmers, water users, and environmental regulatory agencies. The resources most vulnerable to contamination must be identified to effectively regulate and guide agricultural chemical use. Educational programs, technical assistance, and detailed monitoring studies must also consider the vulnerability of groundwater resources.

The U.S. Environmental Protection Agency (USEPA) has proposed a strategy to regulate pesticide use to prevent unacceptable contamination of groundwater resources (USEPA 1993). The agency recommends managing pesticide use on the basis of groundwater use, value, and vulnerability; and it recommends using groundwater vulnerability as a basis for county- or state-level regulatory measures, which could include local banning of specific pesticides. Insufficient protection of a groundwater resource from agricultural chemicals could result in contamination of the drinking water supply and the environment. Excessive protective measures, however, could result in unnecessary economic hardship for the agricultural community. The optimum level of protection must balance responsible use of agrichemicals with the protection of vulnerable groundwater resources.

Two out of three acres of rural Illinois are treated with pesticides. Illinois farmers apply approximately 50 million pounds of pesticides (Pike et al. 1991) and 1 million tons of nitrogen fertilizer yearly (IDOA 1990). In 1990, more than 80 percent of the corn acreage and almost 30 percent of the soybean acreage receiving preplant or preemergent weed control was treated with herbicides that pose a potential hazard to groundwater in vulnerable soil and hydrogeologic settings. Groundwater is the only source of drinking water for about 97 percent of the rural population in Illinois (Withers et al. 1981). Aquifers occur within 50 feet of the surface in about 40 percent of rural Illinois. Results from a statewide survey of rural, private water wells in Illinois suggest that approximately 12 percent of the wells contain detectable levels of pesticides, and approximately 30 percent contain detectable levels of nitrate (Goetsch et al. 1992). Results from another Illinois study of rural, private water wells found that wells located in areas having aquifers within 20 feet of the land surface had a higher likelihood of pesticide or nitrate contamination than wells located in areas having no aquifers within 50 feet of the land surface (Schock et al. 1992).

This report and the accompanying set of maps are a revision of *Potential for Agricultural Chemical Contamination of Aquifers in Illinois* (McKenna and Keefer 1991). The original report and maps were produced in response to the need to predict the sensitivity of Illinois aquifers to contamination through the agricultural use of pesticides and nitrogen fertilizers. Because of the lack of a suitable statewide soils map, the previous publication used depth to the uppermost aquifer material as the sole criterion for evaluating aquifer sensitivity. Since the publication of the previous report and maps (McKenna and Keefer 1991), Schock et al. (1992) confirmed that depth to the uppermost aquifer can be a useful criterion for evaluating the probability of contamination of rural, private well water by agricultural chemicals.

In 1991, the Soil Conservation Service (SCS) released a computerized soil association map and database for Illinois (USDA 1991). The detail and accuracy of this soils map is well suited to the statewide evaluation of soil factors relevant to the control of agrichemical leaching to groundwater. Availability of the publications by Schock and the SCS, together with the growing regulatory pressure to address agrichemical use and related groundwater protection issues, prompted the revision of the previous map (McKenna and Keefer 1991).

This report describes the rationale and methods used to develop a series of statewide and county maps describing the leaching characteristics of soils and the sensitivity of aquifers to contamination by pesticides and nitrate. These maps are published in the Illinois State Geological Survey Open File Series:

> *Nitrate Leaching Classes of Illinois Soils*, by Donald A. Keefer, scale 1:500,000, Open File Series OFS 1995-2.
>
> *Aquifer Sensitivity to Contamination by Nitrate Leaching in Illinois*, by Donald A. Keefer, statewide map, scale 1:500,000, Open File Series OFS 1995-3S.
>
> *Aquifer Sensitivity to Contamination by Nitrate Leaching in Illinois*, by Donald A. Keefer, county maps, scale 1:250,000, Open File Series OFS 1995-3C.

Pesticide Leaching Classes of Illinois Soils, by Donald A. Keefer, scale 1:500,000, Open File Series OFS 1995-4.

Aquifer Sensitivity to Contamination by Pesticide Leaching in Illinois, by Donald A. Keefer, statewide map, scale 1:500,000, Open File Series OFS 1995-5S.

Aquifer Sensitivity to Contamination by Pesticide Leaching in Illinois, by Donald A. Keefer, county maps, scale 1:250,000, Open File Series OFS 1995-5C.

SUBSURFACE FATE OF AGRICULTURAL CHEMICALS

Like that of any land-applied chemical, the fate of pesticides and nitrate is controlled by many processes that occur on and below the land surface. Processes important to pesticide fate include runoff, leaching, volatilization, adsorption to soil particles, and chemical or microbial degradation. Processes important to the fate of nitrogen fertilizer include nitrate leaching and the microbially controlled processes of nitrogen fixation, nitrification, and denitrification. The impact of these processes on the leaching of any compound is also dependent upon four factors: (1) the application rate, formulation, and timing of pesticides and fertilizers; (2) characteristics of the applied compounds; (3) climatic variables; and (4) a range of soil and geologic material factors.

The complete evaluation of these variables and their impact on pesticide and nitrate fate is beyond the scope of this report. This discussion provides insight into this complex environment. The Soil Conservation Service, now called the Natural Resources Conservation Service, and the University of Illinois Cooperative Extension Service can provide additional information regarding the importance of these variables on the movement of agrichemicals.

Impact of Application Rate, Formulation, and Timing

All other variables being equal, the more of a compound applied to the soil surface, the more that is available for leaching to groundwater. It is difficult to predict the fertilizer application rate that results in large nitrate concentrations in groundwater because crop residue, root mass, soil microbes, and other soil organic matter can also be nitrate sources. However, because approximately 100 lb/acre of nitrogen is removed in corn grains (Anderson et al. 1987), application rates exceeding 100 lb/acre will provide a surplus of nitrogen to the soil. This surplus can be lost from the soil through denitrification or leaching, or it can be immobilized and stored in soil microbes. Pesticide application rates are generally determined by the toxicity to the target pest. The recommended application rates for pesticides can vary widely (table 1).

Table 1 Recommended application rates for common herbicides (Humberg et al. 1989).

Common name	Trade name	Recommended application rate (lb/acre)
Alachlor	Lasso	1.5 to 8.0
Atrazine	Aatrex	2.0 to 4.0
Bentazon	Basagran	0.75 to 2.0
Metolachlor	Dual	1.5 to 4.0
Metribuzin	Sencor	0.25 to 1.0
Simazine	Princep	2.0 to 4.0
Trifluralin	Treflan	0.5 to 1.0

The formulation, method, and timing of application also affect the leachability of pesticides and nitrate. In general, the earlier a compound is applied to the surface before planting, the more opportunities there are for leaching. This holds for both pesticides and nitrate. The formulation applied can also have an impact on leaching. For example, if a nitrogen fertilizer is applied in the fall, the use of ammonium nitrate will probably contribute more to nitrate leaching than will anhydrous ammonia or urea. In addition, delaying this application until the spring would probably further reduce nitrate leaching because half the nitrogen in ammonium nitrate is in the form of ammonium (NH_4^+), which sticks (adsorbs) to soil particles, and half is already in the form of nitrate (NO_3^-), which can leach with the first rainfall following application.

Impact of Chemical Characteristics

Pesticides The tendency for a pesticide applied at the land surface to move through the soil is affected primarily by the persistence of the pesticide in the soil, the solubility of the compound in

water, its tendency to stick (adsorb) to soil organic matter and clay particles, and its tendency to volatilize. *Pesticide* persistence refers to the loss of a pesticide through the combined effects of chemical and microbial degradation. In these situations, degradation does not require the complete breakdown of a pesticide into nontoxic compounds, but includes any alteration of the original active ingredient.

The *water solubility* of a pesticide is the amount of the compound (solute) that can remain dissolved in a given volume of water. The greater the solubility of a compound, the more of it that is likely to leach downward during a rainfall, potentially contaminating groundwater resources.

Adsorption is a combination of several processes that cause a pesticide to adsorb to the surface of soil organic matter or a clay particle, thus retarding the movement of the pesticide relative to water movement in a soil. Pesticides are more likely to adsorb to soil organic matter than to clay (Hassett and Banwart 1989). However, when little organic matter is present (i.e., less than 1 percent), clays become important adsorption sites. A pesticide molecule that adsorbs to a soil particle is generally considered to be able to desorb (unstick) when its dissolved concentration in the surrounding soil water decreases. However, Roy and Krapac (1994) demonstrated that, for some pesticide–soil combinations, soil-water concentrations may need to decrease significantly below adsorption levels for significant desorption to occur; and a fraction of adsorbed pesticide may not desorb. Although adsorption seems to be an important process for restricting pesticide movement, there have been many observations of pesticides at depths greater than those predicted using the commonly held adsorption theories (Hallberg 1989, Schock et al. 1992). The reasons for this rapid movement are currently unclear.

Volatilization is the change in state of a pesticide molecule from solution to the soil gas or atmosphere. The likelihood of pesticide volatilization is described by the Henry's Law constant of the compound. Volatilization generally increases with rising temperatures. Some pesticides applied to wet soils volatilize more rapidly than the same pesticides applied to dry soils (Guenzi and Beard 1974).

Nitrate Nitrate (NO_3^-) is a nitrogen-containing molecule with a charge of −1. This negative charge gives it a much greater mobility through the soil than the inorganic nitrogen molecules ammonia (NH_3) and ammonium (NH_4^+). Although ammonia has a neutral charge, it is relatively unstable in the presence of soil water and quickly changes to ammonium. The +1 charge of ammonium causes it to adsorb readily to the negatively charged clay and organic matter in the soil. This adsorption prevents ammonium from leaching readily through the soil. Nitrate, however, is repelled by the negatively charged soil particles and therefore will move with the soil water and into the groundwater. Because nitrate is very soluble and is not lost directly by volatilization, any nitrate in the soil is generally vulnerable to plant uptake, leaching, or denitrification.

Although an extensive discussion of the nitrogen cycle within an agricultural soil is outside the scope of this report, a brief discussion is necessary for clarity. Nitrogen is recycled in the environment through mineralization, immobilization, fixation, denitrification, and nitrification (fig. 1). In the soil, these processes are mainly controlled by microbes, although plants are also able to fix (or extract) nitrogen gas directly from the soil gas or atmosphere.

The fall and early spring are likely to offer many opportunities for nitrification, and there will be little to no crop use of nitrate. The production of a nitrate surplus, without any use of that surplus, provides ideal conditions for nitrate leaching if enough water is supplied through precipitation. Fall application of ammonium nitrate provides a large potential for nitrate leaching because some nitrate is directly applied and there is no crop demand for it until after crop emergence in late spring or early summer.

Climatic Influences

Climate plays a large role in affecting the movement of agrichemicals through soil. The main climatic variables important to this discussion are precipitation and temperature; minor variables include wind speed, relative humidity, and solar radiation. These variables influence leaching of compounds to the water table, microbial degradation and alteration of pesticides and nitrogen, removal of water from the soil through evaporation and transpiration, loss of pesticides through volatilization, removal of nitrogen gas from the soil-gas system, and loss of near-surface compounds through runoff and erosion.

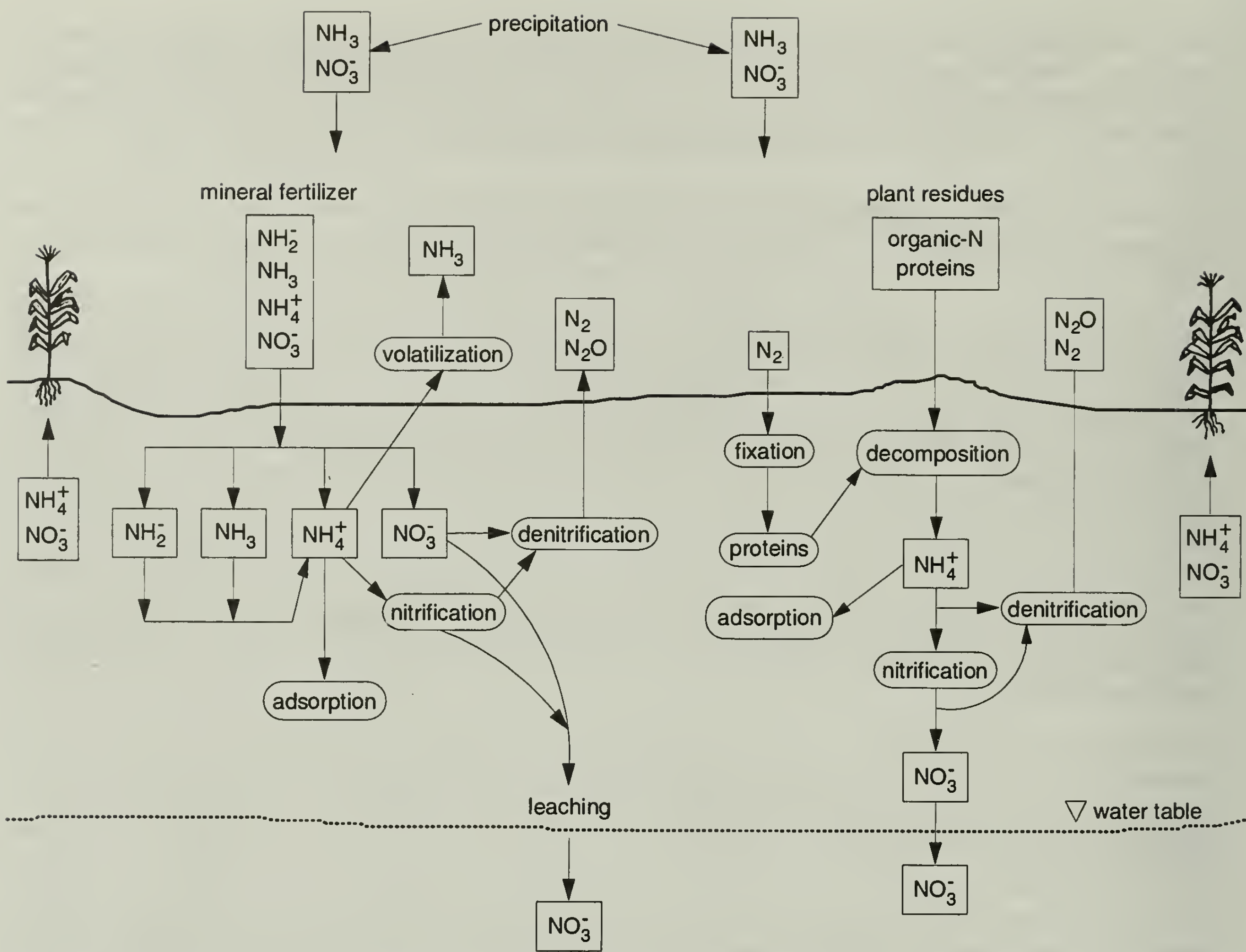

Figure 1 The nitrogen cycle in agricultural soils (modified from Freeze and Cherry 1979).

In any rain storm, the intensity and the total amount of rainfall help determine how the water will move into and through the soil. The prestorm moisture conditions in the soil also help determine the water-movement characteristics. Generally, the lower the rainfall intensity and the drier the prestorm moisture conditions, the more likely that all the rain will infiltrate the soil and move downward through the soil matrix pores. (Soil matrix pores are the small pores between the individual soil particles. Macropores are large elongated pores that occur because of roots, earthworms, or drying of the soil.) When the rainfall rate exceeds the rate of infiltration into the soil, the excess water will accumulate, or pond, on the soil surface. If water continues to collect, it will eventually flow off the field as runoff.

When the rainfall intensity approaches or exceeds the infiltration rate, water can move through both the matrix pores and the macropores in the soil. The elongated macropores tend to allow water and agrichemicals to move rapidly through the soil. In a single storm, water and transported compounds can easily move through macropores to a depth of 1 meter, even in fine grained soils (Quisenberry and Phillips 1976, Flury et al. 1994).

Whereas rainfall intensity and amount can contribute to rapid leaching of a small fraction of the applied compound, warm sunny days can cause water and compounds to move upward through the soil matrix pores. When crops are growing, evaporative losses can be dwarfed by transpiration losses. Transpiration, the use of water by plants for growth and evaporation through the leaves, can remove water from much greater depths than can evaporation because the depth of crop roots determines the maximum depth of water removal. Together, evaporation and transpiration—or evapotranspiration (ET)—draw water toward the land surface and toward the crop roots, which can effectively return some of the leached compounds back toward the surface.

Finally, rainfall and temperature can affect microbial activity and, therefore, nitrogen alterations and pesticide degradations. Nitrate is applied directly in fertilizer or can be created by altering other forms of nitrogen through the microbially controlled processes of nitrification, immobilization, or nitrogen fixation. Microbial activity is probably highest in the spring and early summer when the soil

is frequently moist and warm because microbial alterations cannot continue if the soil is too dry or too cold. Moist and warm conditions at other times will also contribute to high microbial activity.

Impact of Soil and Geologic Material Characteristics

For this report, *soil* refers to the surficial, weathered portion of the uppermost geologic materials. *Geologic materials* are all lithified and nonlithified deposits, including the soil. Two properties of geologic materials are most important in affecting water and compound movement: the amount of organic matter present and hydraulic conductivity (sometimes called permeability). The most important adsorption site for pesticides is organic matter. Under ideal conditions, organic matter will retard the downward movement of pesticides through adsorption. The adsorbed pesticides can be released (desorbed) at a later time and continue to move downward. The rate at which pesticides adsorb and desorb from organic matter is related to the amount of a compound dissolved in the surrounding soil water. Larger pesticide concentrations in the soil water generally result in increased adsorption (Hassett and Banwart 1989). As the dissolved pesticide moves downward with percolating soil water, the dissolved concentration of pesticide in the remaining soil water should decrease and the adsorbed pesticides desorb accordingly. Studies have shown, however, that with time, bound or adsorbed pesticides tend to become resistant to leaching (Pignatello and Huang 1991).

Hydraulic conductivity, a property of porous geologic materials, relates to how easily water can move through the material and helps predict how far water and compounds will move under a given water-pressure gradient. Unfortunately, the presence of macropores complicates the measurement and application of hydraulic conductivity values. Most methods that measure the hydraulic conductivity of a geologic material containing macropores actually provide a combined measure of the conductivity of both the matrix porosity and the macroporosity. The hydraulic conductivity of the matrix cannot reliably be separated from that of the macropores in these measurements. The combined measurement, however, does not describe how water is actually moving through the soil matrix pores and macropores. Regardless of the difficulties involved with accurately characterizing the separate hydraulic conductivities, macropores increase the overall hydraulic conductivity of the geologic material, which increases the downward movement of water and compounds. Recent field studies conducted by the Illinois State Geological Survey suggest that water and compounds are more likely to move through macropores associated with plant roots than macropores associated with soil structure or earthworms. The reason for this difference is not known.

GROUNDWATER AND AQUIFERS IN ILLINOIS

Groundwater

Groundwater is water that occurs within the saturated zone of geologic materials and where the fluid pressure of the water is equal to or greater than atmospheric pressure (IGPA 1987). The *water table* is a surface in the saturated zone where the fluid pressure equals atmospheric pressue and is easily determined by the level at which water stands in an open well or hole that penetrates into the saturated zone. For significant parts of the year in Illinois, the water table is roughly parallel to, and within 5 feet of, the land surface in most fine grained soils.

Above the water table is the *unsaturated zone* where many of the soil pores are filled with air rather than water. The fluid pressure of water in the unsaturated zone is less than atmospheric pressure, so this water will not flow into an open well or borehole. The amount of water in the unsaturated zone can vary significantly. In the spring, frequent or heavy rain storms can raise the water table to or just below the land surface, thereby almost eliminating the unsaturated zone.

The Illinois Groundwater Protection Act (IGPA) called for the development of a classification system for groundwater. The IGPA recognized that groundwater is present in various types of hydrogeologic settings and has varying background quality levels. The Illinois Administrative Code (35 IL Admin. Code, Subpart B, Sections 620.210 through 620.240) defines four classes of groundwater in Illinois:

Class I: Potable Resource Groundwater

Class II: General Resource Groundwater

Class III: Special Resource Groundwater

Class IV: Other Groundwater

Aquifers

Aquifers are groundwater-saturated geologic materials that have a hydraulic conductivity great enough "to provide economically useful quantities of water to wells, springs or streams" under ordinary gradients (differences) in water pressure (IGPA 1987). This definition suggests that a deposit may qualify as an aquifer for a single residence, while not qualifying as an aquifer for a municipal supply well. Generally, aquifers in Illinois include geologic deposits such as sand, sand and gravel, sandstone, and fractured carbonates (limestone and dolomite). The groundwater classifications were defined so that any aquifer with potable water is a source of Class I Groundwater. Fine grained materials such as glacial tills, shales, and unfractured carbonates would not qualify as aquifers because they generally cannot replenish water quickly enough to wells, springs, or streams. Dug or bored wells are frequently constructed in these nonaquifer deposits to collect quantities of groundwater sufficient for private supplies. Because the recharge rate is so slow, these wells are actually serving in part as cisterns or storage tanks. The condition in the IGPA definition that aquifers must supply sufficient quantities to springs or streams, in addition to wells, makes it clear that fine grained deposits cannot be considered aquifers for any purpose. Any potable groundwater resources in fine grained deposits will, therefore, be in one of the other three classes of groundwater, depending upon the other considerations listed in the statutes.

Groundwater Contamination

Leaching of pesticides and nitrate below the root zone is an issue of public and environmental health. The presence of pesticides and nitrate in drinking water can be due to groundwater contamination, aquifer contamination, or well-water contamination. Each type of contamination must be understood before the detection of agrichemicals in water supplies can be properly understood.

Groundwater contamination is the presence of pesticides, nitrate, or other contaminants below the water table. This definition of contamination carries no health-related implications. In other words, groundwater or well water can be contaminated by a compound, and yet the compound can be present at a concentration below established health-based standards.

Groundwater contamination does not necessarily include or cause contamination of aquifers or well water, although aquifers and well water may become contaminated following the contamination of groundwater. Figure 2 illustrates routes for water and agrichemicals to move past the water table. In addition, transpiration by plants can draw water and compounds back up into the plant or into the unsaturated zone. Water and agrichemicals can also move into a drainage tile or directly into a stream or river, thus contributing to contamination of surface water systems. Water and compounds that leach past the water table can also stay in the saturated zone.

Aquifer Contamination

Aquifer contamination occurs when water, agrichemicals, or other contaminants move into an aquifer. The top of this deposit can be significantly below the land surface (fig. 2), or it can be the uppermost geologic material. Depth to the top of the aquifer affects whether or how much of a contaminant is likely to leach into the aquifer because the compound can be slowed down by adsorption, removed by microbial degradation, or diluted before it reaches an aquifer at depth.

Well-Water Contamination

Well-water contamination can occur by three routes (fig. 2), one of which can be a contaminated aquifer. Well water can easily become contaminated by shallower sources, however, if the grout or cement—installed to seal the well casing—is cracked or leaking. If this happens, contaminated groundwater from above the aquifer can move down along the well casing and into the well. Finally, if the ground surface is graded toward the well and the grout around the well head is not properly sealed, then contaminated runoff can reach the well head and travel down along the cracked casing and into the well.

Recent studies in Illinois have shown that the probability of well-water contamination is related to the type of well construction (Schock et al. 1992, Goetsch et al. 1992). Dug or bored water wells have significantly greater rates of occurrence of agrichemicals than drilled wells. In addition, when compounds are found in dug or bored wells, their concentrations are generally larger than in drilled wells. Because dug or bored wells are generally finished in nonaquifer materials (such as glacial tills), predicting the vulnerability of these wells to contamination is difficult. Nearby activities (e.g., pesticide mixing, septic tank leach fields, livestock confinement) may play a larger role in affecting

water quality in dug and bored wells than in drilled wells. Despite the widespread use of dug and bored wells for private water supplies in rural areas, the maps generated for this project are designed only to predict the sensitivity of aquifers to contamination by agrichemicals. They cannot be used to predict water quality in dug or bored wells.

EVALUATING AQUIFER SENSITIVITY TO AGRICHEMICAL CONTAMINATION

This project was undertaken to provide a set of maps to assist State efforts at protecting groundwater resources from contamination by unsafe concentrations of pesticides and nitrate. A useful predictive tool for protecting groundwater should not consistently under- or over-predict aquifer sensitivity to contamination. For maximum flexibility and consistency, an aquifer sensitivity model should be applicable to both statewide and farm-level data. These considerations were used when reviewing possible modeling approaches and developing the model used in creating the maps.

Modeling Approaches

The models developed to predict the movement of agrichemicals in and through the crop root zone can be divided into two groups: solute transport models and interpretive mapping models.

Solute transport models Solute transport models use mathematical equations to predict water movement and the transport and fate of specific compounds (Voss 1984, Wagenet and Hutson 1987). Some models are developed to provide insight to the detailed physics controlling the behavior of water and agrichemicals in the subsurface; they utilize various physical, chemical, microbiological, and hydraulic parameters to describe the water and compound fate. These detailed models are generally too expensive and too complicated to be used by most people. Because these models are primarily designed to predict high-resolution behavior for research at specific test plots, they may also not be appropriate for screening or planning purposes for larger areas.

Other solute transport models have been developed primarily to assist in designing agricultural management practices that would minimize the movement of agrichemicals below the root zone (Carsel et al. 1985, Leonard et al. 1987, Knisel 1980). In these models, the equations describing compound transport focus on generalized relationships between water and compound movement through the soil profile. These models frequently have fewer parameters and are generally easier to use than the more detailed, mathematical models.

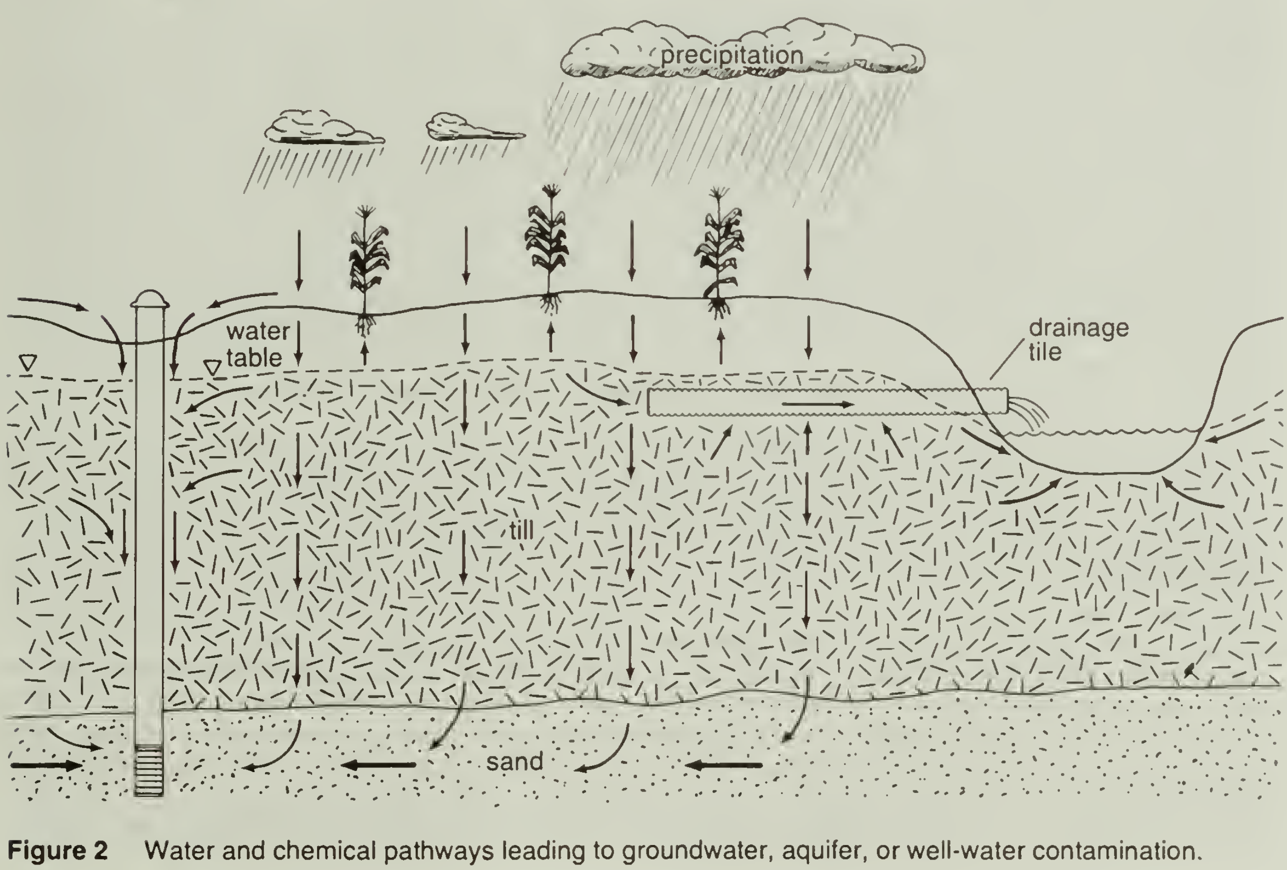

Figure 2 Water and chemical pathways leading to groundwater, aquifer, or well-water contamination.

Interpretive mapping models Interpretive mapping models evaluate the likelihood of pesticide and nitrate movement to groundwater or aquifers by combining different mapped layers such as soil associations, geologic materials, landscape characteristics, or agrichemical use information (Aller et al. 1985, Berg and Kempton 1988, Keefer and Berg 1991, Soller and Berg 1992). By design, these interpretive mapping models depend on the availability of mapped data for the needed variables. These models are useful for large-scale screening purposes, but are dependent upon data accuracy for farm-level predictions of contaminant movement. These interpretive maps generally do not address many of the factors that affect compound fate and transport, but they can provide qualitative predictions of agrichemical leaching characteristics or the senstivity of groundwater or aquifers to contamination. .An evaluation of these two modeling approaches indicated that interpretive mapping is best suited for this project.

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Two statewide data sets were identified as containing information that would be useful for producing aquifer sensitivity maps: a soil association map and database (USDA 1991) and a map of geologic materials to a depth of 50 feet (Berg and Kempton 1988). The soil association map and database were used in two different interpretive mapping models that generated maps of nitrate leaching classes and pesticide leaching classes. The geologic map was used to create a map of depth to the uppermost aquifer. The nitrate leaching classes map was combined with the depth-to-aquifer map to create a map of aquifer sensitivity to contamination by nitrate leaching. Finally, the pesticide leaching classes map was combined with the depth-to-aquifer map to create a map of aquifer senstivity to contamination by pesticide leaching.

The development of the interpretive maps in this project was made possible through the use of a computerized mapping system known as a geographic information system (GIS). GIS technology allowed graphical files, such as maps, to be entered into a computer and combined with other map information or with tabular database files. Using this GIS, two maps, each illustrating the distribution of a single soil variable, were overlaid to produce a new map. This new map delineated areas that correspond to the combinations of the two soil variables. GIS technology also allowed the distribution of any mapped variable (e.g., hydraulic conductivity of the surface horizon) to be analyzed, as in a frequency analysis of hydraulic conductivity values. This analysis allowed the values for any map to be grouped using rules defined by an interpretive mapping model and classified for easier evaluation of the combined information.

Mapping conventions ***Soil association map*** The soil association map is part of a national Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) effort to develop generalized soil maps for each state. Because of the wide variability of soils across a landscape and this map's small scale, the map illustrates the distribution of soil *associations* throughout Illinois, not soil phases. (A soil *phase* is a subdivision of a soil series and is the map unit used most often in mapping soils at a detailed scale. A soil phase identifies the slope and soil series present and, where relevant, indicates the degree of erosion for the delineated area.) This new soil association map was developed by combining the individual soil association maps from the detailed county-level soil surveys. Each soil association is a group of three to 21 soil phases. A database accompanying the map contains detailed information describing many characteristics for each soil association and for each soil phase, detailed characteristics for each soil horizon (up to seven) within each soil phase, and information on the extent of each soil phase within each soil association, expressed as the percentage of the association that is covered by each soil phase (USDA 1991).

To develop interpretive maps for predicting agrichemical leaching, it was necessary to describe with a single value the selected soil properties for each soil association. To describe the percent slope for a soil association composed of 18 soil phases meant that the percent slope of the phases must be averaged, and this average assigned to represent the entire association. A review of the values for several soil properties was conducted and showed that the distributions of values in any association were irregular and unpredictable. Frequently, most values for a given property clustered around some middle value(s); a few values deviated widely. Because the values for different soil properties ranged from precise numbers (e.g., hydraulic conductivity) to imprecisely scaled names (e.g., natural drainage class), it was not possible to determine an arithmetical average (mean) value for every property. Given the unpredictable nature and the variability in measurement scales of the soil properties, the middle (median) value was determined to be most appropriate for representing each soil association. The median value for any set of measurements is the middle (or 50th percentile) value if the measurements are sorted from lowest to highest. It was possible to determine

a median value for any soil property because information was available about the percent coverage of each soil phase for every soil association. Determining the median value of a soil variable (e.g., percent slope) for any soil association required first listing the soil phases for each association (table 2, Initial order), then sorting according to the values of percent slope (table 2, Sorted order). The information on percent coverage of each soil phase could then be used to determine the slope of the soil phase containing the median value. In this example, the soil phase with the median value is soil phase number 1, which has a slope of 3.2 percent. This slope value of 3.2 percent is then assigned to represent the entire association, IL001.

Table 2 Assignment of median values to soil associations.

Soil association	Soil phase	Percent slope	Percent coverage
A - Initial order			
IL001	1	3.2	10
	2	2.0	45
	3	6.1	7
	4	4.5	38
B - Sorted order			
IL001	2	2.0	45
	1	**3.2**	**10 (median value)**
	4	4.5	38
	3	6.1	7

The median value does not provide information regarding the range in values for any soil property within a soil association. Because the values for any soil property vary with each soil phase and the phase values vary within each association, some measure of variability in the soil properties would provide more information on the distribution of the property throughout the state. Again, given the unpredictable nature and the variability in measurement scales of the soil properties, a simple measure of the range in values was preferred as opposed to a traditional estimator such as the standard deviation. For any soil property, because a small area of most associations is occupied by soil phases with extreme values, a measure of the total range in values would be biased by these extremes. If the values for the upper and lower 10 percent of coverage were removed from consideration, the remaining values could be used to provide a 10 percent trimmed range. This trimmed range is not influenced by extremely high or low values that only occupy a small fraction of an association. For example, in table 2, the values for the top and bottom 10 percent were ignored and the values for the remaining 80 percent were considered. In this example, the percent slope of the 11th percentile is 2.0 percent, and the 89th percentile is 4.5 percent, resulting in a trimmed range of 2.5 percent. Coincidently, this is the same value that would have resulted if the range were calculated using all available values. This procedure was used to display the ranges in soil property values considered for and incorporated into the interpretive maps.

Depth-to-aquifer map The other map utilized for this project was a map of depth to the uppermost aquifer within 15 meters (50 feet) of the land surface. The *Depth to Uppermost Aquifer in Illinois* map (pl. 1) was derived from the computerized version of the *Stack-Unit Map of Illinois to a Depth of 15 Meters* (Berg and Kempton 1988). Several mapping conventions were used to produce the stack-unit map and are incorporated into the depth-to-aquifer map. The stack-unit map only identified deposits that were 1.5 meters (5 feet) thick or greater, unless they were generally present for at least 1 square kilometer.

Highly permeable geologic deposits within 50 feet of the land surface may not always be completely saturated with groundwater and hence may not qualify as aquifers under the IGPA. Given the same rainfall input, water movement through soil matrix pores is much faster through unsaturated aquifer materials than through unsaturated nonaquifer materials. This suggests that the degree of saturation of these deposits will not significantly change their relative contaminant transport characteristics. Therefore, this study refers to all highly permeable geologic materials as aquifers, while recognizing

that because of their degree of saturation, some of these materials periodically may not meet the official IGPA definition of an aquifer.

Deposits classified as aquifers include sand, sand and gravel, sandstones, and fractured limestone or dolomite that meet the mapping criteria for the stack-unit map. Some sand and gravel deposits shown on the stack-unit map are thin and locally absent. Other sand and gravel deposits, while continuous, are thin (less than 20 feet thick) and so near the land surface that they are unsaturated for parts of the summer. Because these deposits may not meet the water needs of most users, they are not recognized as aquifers for this study. Deposits otherwise classified as nonaquifers include windblown silts, low-conductivity glacial tills, shale, and nonfractured limestone or dolomite.

The stack-unit map delineates geologic units using a recognized classification system partly based on interpretations of the average texture of each nonlithified (nonbedrock) unit and the average degree of cementation and fracturing of each bedrock unit. This system did not incorporate hydraulic conductivity values or other hydraulic properties of the deposits.

Because the stack-unit map defined units based on their average properties, it provided no indication of the variability in texture, degree of cementation or fracturing, or variations in hydraulic conductivity within a given unit. All geologic materials vary in these properties. Because these variations were not accounted for within the stack-unit map, they cannot be delineated by the depth-to-aquifer map derived from the stack-unit map, and these properties are therefore assumed to be uniform throughout each unit. This assumption allows for identification of map units as either aquifers or nonaquifers. The known variability in these properties and the corresponding variations in other contaminant transport parameters (e.g., percent organic matter, porosity, presence of macropores) should be considered when using the agrichemical leaching maps described in this publication.

Potential for nitrate contamination of Illinois aquifers The development of a map evaluating the potential for nitrate contamination of Illinois aquifers was separated into two steps. First, a map was developed for predicting nitrate leaching classes of Illinois soils. This step utilized several variables from the soil association map and database. Second, this nitrate leaching map was combined with the depth-to-aquifer map to produce a map of aquifer sensitivity to nitrate leaching. The models used to create these interpretive maps were developed specifically for this project.

Nitrate leaching classes of Illinois soils A review of existing maps or databases found that no suitable information was available for predicting the background nitrate contributions from various soils, nor was information about the distribution of nitrogen fertilizer use available on a suitable scale or level of detail. Accordingly, only soil factors could be used to evaluate the probability of nitrate leaching. A model, developed to evaluate this probability, combined several soil variables from the soil association map and database.

To develop a map showing the nitrate leaching characteristics of Illinois soils, it was necessary to consider soil properties relating to the water movement characteristics of the soil and the likelihood for water movement below the root zone. The following were specifically considered: hydrologic soil group, available water capacity, shrink-swell capacity, texture, drainage class, hydraulic conductivity of each soil layer, slope, nature of the water table, seasonal depth to the water table, occurrence of a fragic horizon, depth and degree of soil development, and soil taxonomic classification.

Analyzing the suitability of these soil properties for use in the nitrate maps revealed that information on seasonal depth to the water table, nature of the water table, and shrink-swell capacity was not complete for every soil in the database. Consequently, these properties were unusable for this statewide effort. Other variables, including taxonomic classification and depth of soil development, contributed ambiguous information with respect to leaching characteristics. The soil hydrologic group was a variable that appeared relevant to nitrate leaching, but was also a function of several other relevant variables (i.e., hydraulic conductivity, drainage class, available water capacity). The hydrologic group was not used because its relationships with other variables would have made it difficult to weight appropriately. (The use of interdependent variables in interpretive maps can easily result in disproportionately high weighting of some variables, resulting in unseen biases or errors in the interpretations.)

The texture of each soil horizon was identified as a possible indicator of the soil hydraulic conductivity. However, hydraulic conductivity was already provided by the database, so texture was dropped from consideration because it would not provide any new information. Other soil variables,

including slope and degree of soil development, provided information important for leaching characteristics of only some soils.

The relevant soil variables that were reliable for estimating the leaching potential of all soils were hydraulic conductivity of individual soil layers, drainage class, available water capacity of individual soil layers, and presence of a fragic horizon. (A fragic horizon is very resistant to water flow through its matrix pores and so will restrict the downward movement of water and contaminants.) With this evaluation as the basis, the following soil information was initially selected for incorporation in a map of nitrate leaching in Illinois soils: hydraulic conductivity of individual soil layers, drainage class, available water content of individual soil layers, presence of a fragic horizon, slopes greater than or equal to 15 percent, and soils with thin profiles.

Once the variables were selected, a method was needed to combine them and classify the resulting information according to differences in the probability of nitrate leaching. The first step in this method was to combine the three variables present for every soil, that is, hydraulic conductivity, drainage class, and available water capacity. In the database accompanying the soil association map, hydraulic conductivity and available water capacity had values for each horizon within each soil phase, whereas the natural drainage class was assigned to the entire soil profile.

The incorporation of hydraulic conductivity values in this mapping model was simplified by selecting a single value for each soil phase. A travel time index was developed to consolidate these hydraulic conductivity data into a single value for each profile. This index provided an indication of the rate at which water might move through the entire soil profile for each soil phase. The travel time index was calculated by dividing the thickness (in inches) of each soil horizon by the hydraulic conductivity (inches/hour) of that horizon. Then each of these horizon values was added to provide a travel time index for every soil phase. This approach provided an index value that accounts for the occurrence of one or more horizons with low hydraulic conductivity in a profile. Profiles with two or more low hydraulic conductivity horizons will have longer travel times and, therefore, a lower probability for leaching than profiles with only one low hydraulic conductivity horizon. While it is recognized that the horizon with the lowest hydraulic conductivity limits the downward movement for the entire profile, the presence of high conductivity layers above low conductivity layers increases the probability that significant lateral transport of water and dissolved compounds will occur. Lateral transport is assumed to contribute to a higher probability for downward leaching at some lateral distance, where the lower restrictive layer is likely to be absent. Because of the large quantity of data and the difficulty in evaluating specific layering conditions, this approach of a single, profile-composite travel time index is adopted for this project. A frequency analysis of the travel time values was used to group them into five classes (table 3).

Table 3 Travel time index.

Travel time index	Thickness / hydraulic conductivity (days)
Very fast	< 1.5
Fast	1.5 to 3.0
Moderate	3.1 to 14.0
Slow	14.1 to 28.0
Very slow	> 28.0

The U.S. Department of Agriculture defines seven natural drainage classes that characterize "the frequency and duration of wet periods under conditions similar to those under which the soil developed" (USDA 1993). These seven classes are primarily based on two criteria: the normal water removal characteristics of the soil and the water-holding capacity of the soil. This classification provides a rough measure of the depth to the seasonally high water table in a profile and its duration. Although this is not important for characterizing nitrate leaching by itself, depth to the water table provides some insight into the ability of infiltrating water (and dissolved compounds) to move through the soil profile. Soils with water tables near the surface for extended periods of time restrict the through-flow of water during these periods. Soils with deep water tables do not restrict through-flow of infiltrating waters. Consequently, soils with seasonally deep water tables have a larger probability of allowing nitrate to leach through the soil profile than soils with a seasonally shallow water table.

The database accompanying the soil association map defines 11 natural drainage classes, four of which are transitional between pairs of the seven classes (e.g., well drained to moderately well drained). These 11 natural drainage classes have been grouped into five drainage classes (table 4). The five drainage classes were defined so that the resulting variability in leaching potential between any two adjacent classes was larger than the variability in leaching potential within any one class.

Initial efforts to classify the available water capacity and combine it with these other two variables showed that available water capacity was significantly less important than the drainage class or the travel time in affecting the probability of nitrate leaching. Available water capacity was so much less important that it did not change the value of any leaching class, determined by the combination of travel time index and drainage class. For this reason, available water capacity was omitted from the analysis.

Table 4 Drainage classes.

Drainage class	Natural drainage class*
Excessive	Excessive Somewhat excessive Somewhat excessive to well
Well	Well Well to moderately well
Moderate	Moderately well
Poor	Somewhat poorly Somewhat poorly to poorly
Very poor	Poorly Poorly to very poorly Very poorly

* USDA 1993

Once the travel time index and drainage classes were established, the nitrate leaching classes could be assigned to each soil phase. The assignment of these classes was a two-step process. First, a preliminary nitrate leaching class was developed by combining the travel time index and drainage class), according to a set of rules defining how the two identified variables were combined (table 5). During this step, any soil that was probably tile-drained was identified. Tile-drained soils have a significantly lower chance of contributing to aquifer contamination from nitrate leaching because much of the leaching nitrate is removed from the groundwater system by the drains. A soil was assumed to have a good probability of being tile-drained if it had a very poor drainage class and at least a moderate travel time index. Soil phases that met these criteria were assigned a preliminary leaching class of *very limited.*

After these preliminary leaching classes were assigned, the second step was to re-evaluate each soil phase and incorporate the other variables likely to affect the probability of nitrate leaching. This re-evaluation established the final nitrate leaching class for each soil phase. The variables that were incorporated at this step included presence of fragic horizons, slopes greater than or equal to 15 percent, and soils classified as either entisols or inceptisols. Evaluation and incorporation of these variables into the leaching classes followed a set of explicit rules. Because fragic horizons greatly reduce the downward movement of water and contaminants through the soil matrix pores, a soil with a fragic horizon was assigned a nitrate leaching class of *limited.*

A soil with a slope of 15 percent or more has a greater potential for runoff than does a soil with a slope less than 15 percent, and therefore has a reduced amount of water available to leach nitrate. Accordingly, the preliminary nitrate leaching class of any soil phase with a slope of 15 percent or greater was lowered by one leaching class in assigning the final class value.

Soils classified as entisols or inceptisols have thinner profiles and, accordingly, may have shallower networks of crop-related macropores. Recent field observations of the importance of crop-related macropores suggested that water and nitrate might not go as deep in these soils as in soils with

Table 5 Preliminary nitrate leaching classes.

Nitrate leaching class	Travel time index	Drainage class
Excessive	Very fast or fast	Excessive
Somewhat excessive	Very fast or fast Moderate	Well or moderate Excessive or well
High	Moderate	Moderate or poor
Moderate	Slow or very slow Very fast or fast	Excessive to moderate Poor
Limited	Moderate to very poor	Poor or very poor
Very limited	Excessive to moderate	Very poor

thicker profiles and deeper crop-related macropores (see page 5). However, the transport of nitrate to depth through macropores has not been identified as important for increasing the amount of nitrate reaching any given depth, as it has with pesticides. The rapid transport of water and nitrate through the soil, however, will at least decrease travel time to a given depth, and may decrease the probability of the nitrates being denitrified or used by plants or soil microbes. The preliminary nitrate leaching class of any soil listed as an entisol or inceptisol, therefore, was also lowered by one nitrate leaching class in assigning the final class value.

Although the percent slope and presence of a thin profile were interpreted as reducing the potential for nitrate leaching, each soil phase could only have its preliminary classification lowered by one class in assigning the final leaching class value. For example, a soil phase with a preliminary nitrate leaching class of moderate was developed on a slope of 20 percent *and* was an inceptisol. It was assigned a final class of limited, not very limited. This constraint was based on a recognition that the nitrate leaching classes are not uniformly scaled with regard to their probability for leaching. A comparison of the leaching characteristics of the travel time indices and drainage classes in each nitrate leaching class suggested that limiting these downward adjustments to one class per soil phase would produce the most consistent class assignments.

One exception was made to these adjustments. If a soil phase had a preliminary nitrate leaching class of excessive, its final classification was not lowered, regardless of its slope or profile thickness. This exception was made because soils with a preliminary class of excessive have such short travel times and are so well drained that the considerations for slope and profile thickness would probably not affect their overall leaching characteristics.

Once the final nitrate leaching classes were assigned to every soil phase, a single median class value was assigned to each soil association (see page 8). The trimmed range values were also determined for the nitrate leaching classes in each soil association (see page 9).

The *Nitrate Leaching Classes of Illinois Soils* map (pl. 2) illustrates the distribution of the six map units, with four classes of trimmed range values as an overprint. The six nitrate leaching classes group the soil associations based on the relative probability of nitrate movement through their profiles. The names of the map units are intended to indicate they are ranked in order of the probability of leaching. All soil associations and their assigned index values are listed in Appendix A. All soil series and their assigned index values are listed in Appendix B.

Aquifer sensitivity to contamination by nitrate leaching The *Nitrate Leaching Classes of Illinois Soils* map was combined with the depth-to-aquifer map by using a set of explicit rules (table 6). The resultant map, *Aquifer Sensitivity to Contamination by Nitrate Leaching in Illinois* (pl. 3), identifies seven map units selected so that each unit represents a group of aquifer settings (sequences of geologic materials with similar water and contaminant transport characteristics) with similar sensitivities to contamination, relative to the other map units. The names assigned to each map unit are only intended to indicate that the units are ranked in order of sensitivity to contamination.

Potential for pesticide contamination of Illinois aquifers The nitrate maps were generated by looking only at the factors that could predict water movement in the soil because the chemical nature of nitrate allows it to move with water. The pesticide maps were created by combining the nitrate map interpretations with information on the distribution of organic matter. (Pesticides are organic compounds that tend to adsorb to soil organic matter, and so have their movement in soil water retarded.) As with the nitrate maps, a map of pesticide leaching classes of Illinois soils was produced first. This pesticide leaching map was then combined with the depth-to-aquifer map to provide a map of aquifer sensitivity to contamination by pesticide leaching.

Pesticide leaching classes of Illinois soils The travel time index and drainage class were carried over from the nitrate maps. Because information on percent organic matter was provided for each horizon in each soil phase, it was necessary to simplify the inclusion of this information in the interpretive map by developing another parameter, the organic matter class. Pesticides are applied to the land surface and are frequently mixed into the soil with a disc or cultivator. The pesticides stay at or near the land surface until the first rainfall because water is necessary for the pesticides to move. The surficial horizon (layer) of each soil is likely to be the most important source of adsorption sites within the whole soil profile because of the pesticide's potentially longer duration in the horizon and the horizon's greater organic matter content. The other horizons will also be important as possible adsorption sites, but the pesticides will only reach them during or after a rainfall. Water and contaminants have been observed to move through macropores to significant depths within a single

Table 6 Aquifer sensitivity to contamination by nitrate leaching.

Aquifer sensitivity	Nitrate leaching class	Depth to uppermost aquifer
Excessive	Excessive to moderate	< 20 feet
High	Limited	< 20 feet
	Excessive or somewhat excessive	20 to 50 feet
Moderate	Very limited	< 20 feet
	High or moderate	20 to 50 feet
Somewhat limited	Limited	20 to 50 feet
	Excessive or somewhat excessive	not within 50 feet
Limited	Very limited	20 to 50 feet
	High or moderate	not within 50 feet
Very limited	Limited or very limited	not within 50 feet

storm (Quisenberry and Phillips 1976, Flury et al. 1994). The potential for adsorption during these storms is significantly reduced, relative to water movement through only the matrix pores, because of the rapid transport times. In addition, the amount of organic matter in Illinois soils decreases dramatically with depth. These considerations lead to the development of organic matter classes that combine information about the amount of organic matter in the surficial horizon with information about the amount of organic matter in the remainder of the profile. The organic matter classes are calculated by first multiplying the thickness of the surficial horizon, in inches, by the percent organic matter in that horizon, to generate the surficial organic matter index. The thickness of each remaining horizon was then multiplied by its corresponding percent organic matter, and these products were added into a subsoil organic matter index. The surficial organic matter index and subsoil organic matter index were combined into five organic matter classes (table 7).

The organic matter classes, travel time index, and drainage classes were combined according to rules described in table 8 to determine the preliminary pesticide leaching classes for each soil phase. Like the preliminary nitrate leaching classes, these classes included soils that were probably tile-drained (see page 12). The final pesticide leaching classes were then assigned by correcting the preliminary class values for the presence of fragic horizons, slopes of 15 percent or greater, and the presence of entisols or inceptisols. For soils with fragic horizons, if the organic matter class was very small, the final leaching class was somewhat limited; if the organic matter class was small, the final leaching class was limited; and if the organic matter class was moderate to very large, the final leaching class was very limited. Following this procedure, the median soil phase values were assigned to each soil association (see page 8), and the trimmed range values were determined for the pesticide leaching classes in each soil association (see page 9).

The *Pesticide Leaching Classes of Illinois Soils* map (pl. 4) shows the distribution of the seven map units with four classes of trimmed range values as an overprint. The six pesticide leaching classes group the soil associations based on the relative probability of pesticide movement through their profiles. Map unit names are intended to indicate that they are ranked in order of the probability of pesticide leaching. All soil associations and assigned pesticide leaching class values are listed in Appendix A. All soil series and assigned pesticide leaching class values are listed in Appendix B.

Table 7 Organic matter classes.

Organic matter class	Surface organic matter index	Subsoil organic matter index
Very large	≥40	all values
Large	20 to < 40	all values
	10 to < 20	≥20
Moderate	10 to < 20	0 to < 20
	5 to < 10	≥20
Small	5 to <10	0 to < 20
	0 to < 5	≥20
Very small	0 to < 5	<20

Table 8 Preliminary pesticide leaching classes.

Pesticide leaching class	Travel time index	Drainage class	Organic matter class
Excessive	Very fast or fast	Excessive	Moderate to very small
	Very fast or fast	Well	Very small
	Moderate	Excessive	Very small
High	Very fast or fast	Well or moderate	Moderate or small
	Moderate	Excessive or well	Moderate or small
	Moderate	Moderate or poor	Very small
Moderate	Very fast or fast	Excessive or well	High
	Very fast or fast	Very poorly	Very small
	Moderate	Moderate or poor	Small
	Slow or very slow	Excessive to moderate	Very small
Somewhat limited	Very fast or fast	Moderate	Large
	Very fast or fast	Moderate or poor	Moderate
	Very fast or fast	Poor	Small
	Moderate	Excessive or well	Large or moderate
	Slow or very slow	Moderate or poor	Small
	Slow or very slow	Excessive to moderate	Very small
Limited	Very fast or fast	Poor	Large or moderate
	Moderate	Moderate or poor	Large
	Slow or very slow	Excessive to moderate	Large or moderate
	Slow or very slow	Poor or very poor	Small
Very limited	Very fast to very slow	Excessive to very poor	Very large
	Very fast to moderate	Very poor	Large to very small
	Slow or very slow	Poor or very poor	Large or moderate

Aquifer sensitivity to contamination by pesticide leaching The new map, *Pesticide Leaching Classes of Illinois Soils*, was then combined with the depth-to-aquifer map using a set of explicit rules (table 9). The resulting map, *Aquifer Sensitivity to Contamination by Pesticide Leaching in Illinois* (pl. 5), includes six map units, selected so that each unit represents a group of aquifer settings with similar sensitivities to contamination, relative to the other map units. The names assigned to each map unit are only intended to indicate that the units are ranked in order of sensitivity to aquifer contamination.

RECOMMENDED USE OF THESE MAPS

The four statewide maps described in this report were developed from two source maps (the stack-unit map and the soil association map) published at a scale of 1:250,000 and should not be enlarged. Both the soil association map and the stack-unit map describe materials that are often highly variable over short distances (e.g., within 1 mile). Accordingly, the maps have been generalized to provide the most information possible without including too much detail in map-unit delineations for efficient use. In addition, the stack-unit map was prepared from a nonuniform data distribution. In some parts of the state, geologic information was available at a greater density (more well logs per township) than others. Accordingly, some areas of the map required more generalization and extrapolation between data points than others. These considerations suggest that the accuracy of the resulting maps is likely to decrease when the area of interest is smaller than some critical area. The large variability in the characteristics of geologic deposits, together with the limited information available from most well logs, causes these maps to have poorly defined confidence limits, so the size of this critical area is unknown. The probability that a land area contains the mapped geologic deposits or soils may be lower for smaller areas than for larger ones. For these maps, evaluations of areas smaller than a township (approximately 36 square miles) are not recommended in order to maintain a confidence level consistent with the published source maps. Evaluations of smaller areas would benefit from additional site-specific information.

Table 9 Aquifer sensitivity to contamination by pesticide leaching.

Aquifer sensitivity	Pesticide leaching class	Depth to uppermost aquifer
Excessive	Excessive to moderate	< 20 feet
High	Somewhat limited or limited	< 20 feet
	Excessive	20 to 50 feet
Moderate	Very limited	< 20 feet
	High or moderate	20 to 50 feet
Somewhat limited	Somewhat limited to very limited	20 to 50 feet
Limited	Excessive or high	not within 50 feet
Very limited	Moderate to very limited	not within 50 feet

Areas with mapped sinkholes are identified on the aquifer sensitivity maps. These areas have been recently mapped (Weibel and Panno, in press) and are included on these maps to indicate areas with more complicated hydrogeologic conditions. Predictions of aquifer sensitivity are more problematic in these areas. Studies being conducted by the ISGS are investigating the nature of water quality and the impact of agrichemical leaching in some of these areas. The results of this research are expected to be available in late 1995. The inclusion of areas with sinkholes on these maps is only made to alert map users to the likelihood of unusual contaminant behavior in these areas.

The maps accompanying this report are designed for statewide evaluation of agrichemical leaching characteristics and associated aquifer sensitivity to contamination. *Aquifer Sensitivity to Contamination by Pesticide Leaching in Illinois* was designed specifically for use in the Generic State Management Plan for Pesticides in Groundwater (IDOA 1994). The four statewide maps are available at a scale of 1:500,000, and individual county maps of the two aquifer sensitivity maps are available at a scale of 1:250,000. The generic management plan includes the aquifer sensitivity map as a tool for predicting the water quality of the aquifers.

The four statewide maps were created, however, to classify soils and aquifer settings according to predictions of leaching potential. The classifications have not been validated by the results of water quality sampling. In addition, the use of these aquifer sensivity ratings as predictors of water quality has not been evaluated. Nonuniform use of pesticides or fertilizers might reduce the reliability of water quality predictions, which can only be validated by careful comparison with water quality data.

A discussion of requirements for validating these maps is outside the scope of this report; however, the Illinois State Geologic Survey and the Illinois State Water Survey recently began an IDOA-funded study to develop validation criteria for the maps and to design and begin installing a dedicated groundwater monitoring well network to validate the map of aquifer sensitivity to contamination by pesticide leaching. Future revisions of these statewide maps will be made if validation efforts indicate it is necessary.

It is the responsibility of the user to determine the appropriateness of these maps for specific applications.

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REFERENCES

Aller, L., T. Bennett, J.H. Lehr, and R.J. Petty, 1985. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings. U.S. Environmental Protection Agency, 600/2-85/018, Ada, Oklahoma, 163 p.

Anderson, C.D., T.J. Bicki, L.V. Boone, W.S. Curran, C.J. Drablos, D.W. Graffis, R.G. Hoeft, E.L. Knake, D.E. Kuhlman, M.D. McGlamery, E.D. Nafziger, T.R. Peck, G.E. Pepper, D.R. Pike, J.C. Siemens, and L.F. Welch, 1987. Illinois Agronomy Handbook: University of Illinois College of Agriculture, Cooperative Extension Service, Circular 1266, 109 p.

Berg, R.C., and J.P. Kempton, 1988. Stack-unit Mapping of Geologic Materials in Illinois to a Depth of 15 Meters: Illinois State Geological Survey, Circular 542, 23 p., 4 plates.

Carsel, F.F., L.A. Mulkey, M.N. Lorber, and L.B. Baskin, 1985. The pesticide root zone model (PRZM)—A procedure for evaluating pesticide leaching threats to groundwater: Ecological Modeling, v. 30, p. 49–69.

Flury, M., H. Fluhler, W.A. Jury, and J. Leuenberger, 1994. Susceptibility of soils to preferential flow of water—A field study: Water Resources Research, v. 30, no. 7, p. 1945–1954.

Freeze, R.A., and J.A. Cherry, 1979. Groundwater: Englewood Cliffs, New Jersey, Prentice Hall, 604 p.

Goetsch, W.D., D.P. McKenna, and T.J. Bicki, 1992. Statewide Survey for Agricultural Chemicals in Rural, Private Water-Supply Wells in Illinois: Illinois Department of Agriculture, Project Summary, 4 p.

Guenzi, W.D., and W.E. Beard, 1974. Volatilization of pesticides, in W.D. Guenzi, J.L. Ahlrichs, G. Chesters, M.E. Bloodworth, and R.G. Nash, editors, Pesticides in Soil and Water: Soil Science Society of America, Inc., Madison, Wisconsin, p. 107–122.

Hallberg, G.R., 1989. Pesticide pollution of groundwater in the humid United States: Agriculture, Ecosystems and Environment, v. 26, p. 299–367.

Hassett, J.J., and W.L. Banwart, 1989. The sorption of nonpolar organics by soils and sediments, in Reactions and Movement of Organic Chemicals in Soils: Soil Science Society of America, Special Publication no. 22, Madison, Wisconsin, p. 31–44.

Humberg, N.E., S.R. Colby, E.R. Hill, L.M. Kitchen, R.G. Lym, W.J. McAvoy, and R. Prasad, 1989. Herbicide Handbook. Sixth Edition: Weed Science Society of America, Champaign, Illinois, 301 p.

Illinois Department of Agriculture, 1990. Illinois agricultural statistics annual summary, 1990: Illinois Department of Agriculture, Division of Marketing, Bureau of Agricultural Statistics, Bulletin 90-1, 124 p.

Illinois Department of Agriculture, 1994. The Generic State Management Plan for Pesticides in Groundwater—DRAFT Release for Public Comment, May 1994.

Illinois Groundwater Protection Act, 1987: Illinois State Statues, P.A. 85-863.

Keefer, D.A., and R.C. Berg, 1991. Potential for Aquifer Recharge in Illinois: Illinois State Geological Survey, map, 1:1,000,000 scale.

Knisel, W.G., editor, 1980. CREAMS: A Field Scale Model for Chemicals, Runoff and Erosion from Chemical Management Systems: U.S. Department of Agriculture, Conservation Service Report 26, 643 p.

Leonard, R.A., W.G. Knisel, and D.A. Still, 1987. GLEAMS: Groundwater loading effects of agricultural management systems: American Society of Agricultural Engineers, Transactions no. 5, p. 1403–1418.

McKenna, D.P., and D.A. Keefer, 1991. Potential for Agricultural Chemical Contamination of Aquifers in Illinois: Illinois State Geological Survey Open File Series 1991-7R, 16 p.

Pignatello, J.J., and L.Q. Huang, 1991. Sorptive reversibility of atrazine and metolachlor residues in field soil samples: Journal of Environmental Quality, v. 20, no. 1, p. 222–228.

Pike, D.R., K.D. Glover, E.L. Knake, and E.E. Kuhlman, 1991. Pesticide Use in Illinois—Results of a 1990 Survey of Major Crops: University of Illinois College of Agriculture, Cooperative Extension Service, DP-91-1, 42 p.

Quisenberry, V.L., and R.E. Phillips, 1976. Percolation of surface-applied water in the field: Soil Science Society of America Journal, v. 40, n. 4, p. 484–489.

Roy, W.R., and I.G. Krapac, 1994. Adsorption and desorption of atrazine and deethylatrazine by low organic carbon geologic materials: Journal of Environmental Quality, vol. 23, p. 549–556.

Schock, S.C., E. Mehnert, M.E. Caughey, G.B. Dreher, W.S. Dey, S. Wilson, C. Ray, S.F.J. Chou, J. Valkenburg, J.M. Gosar, J.R. Karny, M.L. Barnhardt, W.F Black, M.R. Brown, and V.J. Garcia, 1992. Pilot Study—Agricultural Chemicals in Rural, Private Wells in Illinois: Illinois State Geological Survey, Illinois State Water Survey, Illinois Department of Agriculture, Cooperative Groundwater Report 14, 80 p.

Soller, D.R., and R.C. Berg, 1992. A model for the assessment of aquifer contamination potential based on regional geologic framework: Environmental Geology and Water Sciences, v. 19, no. 3, p. 205–213.

U.S. Department of Agriculture, 1991. State Soil Geographic Data Base (STATSGO): U.S. Department of Agriculture, Soil Conservation Service, Miscellaneous Publication no. 1492, 86 p.

U.S. Department of Agriculture, 1993. Soil Survey Manual: U.S. Department of Agriculture, Soil Survey Division, USDA Handbook no. 18, 437 p.

U.S. Environmental Protection Agency, 1993. Guidance for Pesticides and Ground Water State Management Plans: U.S. Environmental Protection Agency, Office of Prevention, Pesticides, and Toxic Substances, (7501 C), EPA 735-B-93-005a, 41 p.

Voss, C.I., 1984. A Finite-Element Simulation Model for Saturated-Unsaturated Fluid-Density-Dependent Ground-Water Flow with Energy Transport or Chemically-Reactive Single-Species Solute Transport: U.S. Geological Survey, Water Resources Investigations Report 84-4369, 409 p.

Wagenet, R.J., and J.L. Hutson, 1987. LEACHMP—A Finite-Difference Model for Simulating Water, Salt, and Pesticide Movement in the Plant Root Zone—Continuum 2: New York State Resources Institute, Cornell University, Ithica, N.Y.

Weibel, C.P., and S.V. Panno, in review. Karstified Carbonate Rock of Illinois: Illinois State Geological Survey, map, 1:500,000 scale.

Withers, L.J., R. Piskin, and J.D. Student, 1981. Ground Water Level Changes and Demographic Analysis of Ground Water in Illinois: Illinois Environmental Protection Agency, 29 p.

APPENDIX A

This appendix lists all of the 81 soil associations included in the soil association map and database used in this study. The listed values for the nitrate leaching class and pesticide leaching class are the median values assigned to the association. The procedure for assigning the median values is discussed on page 8. The leaching class range values are the 10 percent trimmed range values for each association. The procedure for assigning these range values is discussed on page 9.

Soil association (Assoc. number)	Nitrate leach class	Nitrate leach range	Pesticide leach class	Pesticide leach range
PORTBYRON-JOY-SEATON(IL001)	Somewhat excessive	2	Very limited	4
TAMA-MUSCATINE-SABLE(IL002)	Somewhat limited	4	Very limited	2
IPAVA-SABLE-TAMA(IL003)	Limited	4	Very limited	2
HERRICK-VIRDEN-PIASA(IL004)	Limited	1	Very limited	1
COWDEN-OCONEE-DARMSTADT(IL005)	Limited	0	Very limited	1
CISNE-HOYLETON-DARMSTADT(IL006)	Limited	0	Very limited	1
OGLE-DURAND-TAMA(IL007)	High	2	Moderate	2
WAUKEGAN-RICHWOOD-JOY(IL008)	High	2	Somewhat limited	3
BROADWELL-LAWNDALE-ONARGA(IL009)	Somewhat excessive	2	Somewhat limited	2
FLANIGAN-DRUMMER-CATLIN(IL010)	Limited	4	Very limited	2
RUTLAND-STREATOR-WENONA(IL011)	Limited	3	Very limited	1
DRUMMER-PLANO-ELBURN(IL012)	Moderate	4	Very limited	3
WORTHEN-LITTLETON-ELBURN(IL013)	Somewhat Excessive	2	Very limited	1
SAYBROOK-DRUMMER-PARR(IL014)	High	4	Limited	4
PLANO-GRISWOLD-RINGWOOD(IL015)	Somewhat excessive	2	Somewhat limited	3
ELLIOTT-ASHKUM-VARNA(IL016)	Limited	3	Very limited	1
ANDRES-REDDICK-SYMERTON(IL017)	Limited	3	Very limited	1
SWYGERT-BRYCE-CHATSWORTH(IL018)	Limited	0	Very limited	1
CLARENCE-ROWE-CHATSWORTH(IL019)	Limited	0	Very limited	0
PATTON-MARISSA-MONTGOMERY(IL020)	Very limited	2	Very limited	1
MILFORD-MARTINTON-DELREY(IL021)	Very limited	1	Very limited	1
WARSAW-LORENZO-DAKOTA(IL022)	Somewhat excessive	4	Somewhat limited	4
JASPER-LAHOGUE-SELMA(IL023)	Limited	4	Very limited	3
GILFORD-MAUMEE-SPARTA(IL024)	Limited	5	Very limited	3
ASHDALE-DODGEVILLE-TAMA(IL025)	Moderate	2	Very limited	2
CHANNAHON-ROCKTON-FAXON(IL026)	Moderate	1	Very limited	1
KARNAK-JACOB-CAIRO(IL027)	Very limited	4	Very limited	3
SAWMILL-GENESEE-LAWSON(IL028)	Moderate	4	Very limited	3
BEAUCOUP-LAWSON-DARWIN(IL029)	Limited	5	Very limited	1
HOUGHTON-LENA-MUSKEGO(IL030)	Very limited	0	Very limited	0
SEATON-LACRESCENT-LAWSON(IL031)	High	2	Somewhat limited	3
SEATON-HICKORY-MT.CARROLL(IL032)	Somewhat excessive	1	Moderate	1
FAYETTE-ROZETTA-PALSGROVE(IL033)	Somewhat excessive	2	Moderate	4
ROZETTA-FAYETTE-HICKORY(IL034)	Somewhat excessive	1	Moderate	2
ALFORD-MUREN-HICKORY(IL035)	Somewhat excessive	1	High	1
ROZETTA-KEOMAH-HICKORY(IL036)	High	3	Moderate	4
HOSMER-STOY-HICKORY(IL037)	Limited	2	Very limited	3
BLUFORD-AVA-HICKORY(IL038)	Limited	2	Somewhat limited	2

FLAGG-PECATONICA-KENDALL(IL039)	Somewhat excessive	2	Moderate	3
TELL-LAMONT-PORTBYRON(IL040)	Somewhat excessive	3	Somewhat limited	3
MIDDLETOWN-ALVIN-SYLVAN(IL041)	Somewhat limited	1	Moderate	1
FINCASTLE-BROOKSTON-MIAMIAN(IL042)	Moderate	3	Very limited	4
FAYETTE-ST.CHARLES-RADFORD(IL043)	Somewhat excessive	2	Somewhat limited	3
CAMDEN-DRUMMER-STARKS(IL044)	Somewhat excessive	4	Somewhat limited	4
FINCASTLE-SABINA-BIRKBECK(IL045)	Moderate	2	Very limited	2
MIAMI-STRAWN-HENNEPIN(IL046)	High	2	Moderate	3
KIDDER-MCHENRY-PELLA(IL047)	Somewhat excessive	4	Moderate	4
MORLEY-MARKHAM-ASHKUM(IL048)	High	3	Limited	3
BIRKBECK-MORLEY-CATLIN(IL049)	High	4	Somewhat limited	4
FRANKFORT-NAPPANEE-BRYCE(IL050)	Limited	0	Very limited	1
HURST-REESVILLE-PATTON(IL051)	Limited	4	Limited	4
DELREY-MILFORD-SAYLESVILLE(IL052)	Limited	3	Very limited	2
FOX-CASCO-RODMAN(IL053)	Somewhat excessive	5	Somewhat limited	4
EMMA-SEXTON-MARTINSVILLE(IL054)	Moderate	4	Very limited	4
ALVIN-RUARK-ROBY(IL055)	Somewhat excessive	4	Somewhat limited	5
PLAINFIELD-BLOOMFIELD-SPARTA(IL056)	Excessive	0	High	3
COLOMA-SPINKS-OSHTEMO(IL057)	Somewhat excessive	3	High	5
CHELSEA-BOONE-DICKINSON(IL058)	Excessive	4	Excessive	4
PALSGROVE-DUBUQUE-FAYETTE(IL059)	Moderate	3	Very limited	4
GOSS-ALLFORD-BAXTER(IL060)	High	1	Moderate	1
ALFORD-SEATON-HICKORY(IL061)	High	3	Moderate	5
ALFORD-WELLSTON-WAKELAND(IL062)	High	3	Moderate	5
HOSMER-ZANESVILLE-BELKNAP(IL063)	Limited	1	Very limited	1
GRANTSBURG-ZANESVILLE-WELLSTON(IL064)	Limited	1	Limited	3
DERINDA-ELEROY-MASSBACH(IL065)	Moderate	1	Very limited	1
HESCH-BOONE-SHADELAND(IL066)	Moderate	1	Very limited	1
DORCHESTER-WAKELAND-BEAVERCREEK(IL067)	Somewhat excessive	3	Very limited	3
WAKELAND-BIRDS-BELKNAP(IL068)	Limited	3	Very limited	1
BONNIE-BELKNAP-PIOPOLIS(IL069)	Very limited	2	Very limited	0
LENZBURG-MORRISTOWN-RAPATEE(IL070)	Moderate	1	Moderate	3
PLAINFIELD-SPARTA-OAKVILLE(IL071)	Excessive	3	High	4
IPAVA-VIRDEN-HERRICK(IL072)	Limited	1	Very limited	1
CATLAN-DANA-TAMA(IL073)	Somewhat excessive	1	Limited	1
VANPETTEN-CLYDE-PRAIRIEVILLE(IL074)	High	4	Very limited	4
PECATONICA-WHALAN-FLAGG(IL075)	Somewhat excessive	2	Moderate3	
TAMA-ASHDALE-MUSCATINE(IL076)	Somewhat excessive	2	Somewhat limited	3
URBANLAND-MILFORD-ORTHENTS(IL077)	Moderate	2	Somewhat limited	3
URBANLAND-MARKHAM-ASHKUM(IL078)	Moderate	3	Limited	3
URBANLAND-SELMA-OAKVILLE(IL079)	Moderate	4	Somewhat limited	5
HAYNIE-WALDRON-BLAKE(IL080)	Limited	4	Very limited	3
ASHKUM-CHENOA-GRAYMONT(IL081)	Limited	3	Very limited	1

APPENDIX B

This appendix lists each soil series from the soil association database with its assigned nitrate leaching class and its pesticide leaching class. For some series, the database contains multiple phases, where each soil phase is defined by a distinct slope and degree of erosion. The slope or degree of erosion varies so widely within some series that each phase has a different leaching class. When more than one phase is listed in the data base for a soil series, the most sensitive leaching class is assigned to represent the soil series.

Soil series	Nitrate leaching class	Pesticide leaching class
ACKMORE	Limited	Very limited
ADE	Excessive	Limited
ADRIAN	Very limited	Very limited
ALFORD	Somewhat excessive	High
ALGIERS	Limited	Very limited
ALLISON	Somewhat excessive	Limited
ALVIN	Somewhat excessive	High
AMBRAW	Very limited	Very limited
ANDRES	Limited	Very limited
ARGYLE	Somewhat excessive	Somewhat limited
ASHDALE	Moderate	Very limited
ASHKUM	Very limited	Very limited
ASSUMPTION	High	Very limited
ATLAS	Limited	Very limited
ATTERBERRY	Moderate	Very limited
AVA	Limited	Very limited
BANLIC	Very limited	Very limited
BARRINGTON	Somewhat excessive	Somewhat limited
BAXTER	Moderate	Somewhat limited
BEARDSTOWN	Moderate	Very limited
BEASLEY	Limited	Very limited
BEAUCOUP	Very limited	Very limited
BEAVERCREEK	Somewhat excessive	Somewhat limited
BEDFORD	Very limited	Very limited
BEECHER	Limited	Somewhat limited
BELKNAP	Limited	Very limited
BERKS	Limited	Very limited
BINGHAMPTON	Moderate	Limited
BIRDS	Very limited	Very limited
BIRKBECK	High	Somewhat limited
BLACKOAR	Very limited	Very limited
BLAIR	Limited	Moderate
BLAKE	Limited	Very limited
BLOOMFIELD	Excessive	High
BLOUNT	Limited	Limited
BLUFORD	Limited	Somewhat limited
BONNIE	Very limited	Very limited
BOOKER	Limited	Very limited
BOONE	Limited	Limited
BOWES	Somewhat excessive	Moderate

BOYER	Somewhat excessive	Moderate
BREMS	Somewhat excessive	High
BRENTON	Moderate	Very limited
BROADWELL	Somewhat excessive	Somewhat limited
BROOKSTON	Very limited	Very limited
BRYCE	Limited	Very limited
BURNSIDE	Limited	Very limited
CAIRO	Limited	Very limited
CAMDEN	Somewhat excessive	Somewhat limited
CANISTEO	Very limited	Very limited
CARMI	Somewhat excessive	Somewhat limited
CARR	Somewhat excessive	High
CASCO	Somewhat excessive	Moderate
CATLIN	Somewhat excessive	Limited
CHANNAHON	Moderate	Very limited
CHASEBURG	Somewhat excessive	Somewhat limited
CHATSWORTH	Limited	Limited
CHELSEA	Excessive	Excessive
CHENOA	Limited	Very limited
CISNE	Limited	Very limited
CLARENCE	Limited	Very limited
CLARKSDALE	Limited	Limited
CLINTON	High	Somewhat limited
CLYDE	Very limited	Very limited
COHOCTAH	Very limited	Very limited
COLOMA	Excessive	High
COLP	Moderate	Very limited
COMFREY	Very limited	Very limited
COULTERVILLE	Limited	Very limited
COWDEN	Limited	Very limited
CREAL	Limited	Somewhat limited
CROSBY	Limited	Limited
CYCLONE	Very limited	Very limited
DAKOTA	Somewhat excessive	Somewhat limited
DANA	High	Very limited
DARMSTADT	Limited	Very limited
DARROCH	Limited	Very limited
DARWIN	Limited	Very limited
DELREY	Limited	Very limited
DENNY	Very limited	Very limited
DENROCK	Limited	Very limited
DERINDA	Moderate	Very limited
DICKINSON	Excessive	High
DISCO	Excessive	Somewhat limited
DODGE	Somewhat excessive	Moderate
DODGEVILLE	Moderate	Very limited
DORCHESTER	Somewhat excessive	Somewhat limited
DOWNS	Somewhat excessive	Somewhat limited
DRESDEN	Somewhat excessive	Moderate
DRUMMER	Very limited	Very limited
DUBUQUE	Moderate	Very limited

DUNBARTON	Moderate	Very limited
DUPO	Very limited	Limited
DURAND	Somewhat excessive	Somewhat limited
EBBERT	Limited	Very limited
EDEN	Limited	Very limited
EDGINGTON	Very limited	Very limited
EDMUND	Moderate	Very limited
EDWARDS	Limited	Very limited
ELBURN	Moderate	Very limited
ELCO	High	Limited
ELEROY	Moderate	Very limited
ELIZABETH	Moderate	Very limited
ELKHART	Somewhat excessive	Moderate
ELLIOTT	Limited	Very limited
ELSAH	Excessive	High
ELVERS	Very limited	Very limited
EMMA	Moderate	Limited
FAXON	Limited	Very limited
FAYETTE	Somewhat excessive	Moderate
FINCASTLE	Moderate	Very limited
FISHHOOK	Limited	Somewhat limited
FLAGG	Somewhat excessive	Moderate
FLANAGAN	Limited	Very limited
FORESMAN	High	Very limited
FOX	Somewhat excessive	Somewhat limited
FRANKFORT	Limited	Very limited
GENESEE	Somewhat excessive	Somewhat limited
GILFORD	Very limited	Very limited
GINAT	Limited	Very limited
GORHAM	Very limited	Very limited
GOSS	High	Moderate
GRABLE	Somewhat excessive	Somewhat limited
GRANBY	Very limited	Very limited
GRANTSBURG	Limited	Limited
GRAYMONT	High	Very limited
GRELLTON	Somewhat excessive	Moderate
GRISWOLD	Somewhat excessive	Moderate
HARPSTER	Very limited	Very limited
HARRISON	High	Limited
HARTSBURG	Very limited	Very limited
HARVARD	Somewhat excessive	Moderate
HAYMOND	Somewhat excessive	Somewhat limited
HAYNIE	Somewhat excessive	Somewhat limited
HENNEPIN	Moderate	Moderate
HERRICK	Limited	Very limited
HESCH	Moderate	Very limited
HICKORY	Somewhat excessive	High
HIGHGAP	Moderate	Very limited
HITT	Moderate	Very limited
HODGE	Excessive	Excessive
HOLTON	Limited	Very limited

HOOPESTON	Moderate	Very limited
HOSMER	Limited	Very limited
HOUGHTON	Very limited	Very limited
HOYLETON	Limited	Very limited
HUEY	Limited	Very limited
HUNTSVILLE	Somewhat excessive	Very limited
HURST	Limited	Limited
IPAVA	Limited	Very limited
IROQUOIS	Very limited	Very limited
IVA	Moderate	Very limited
JACOB	Very limited	Very limited
JASPER	Somewhat excessive	Moderate
JOLIET	Limited	Very limited
JOY	Moderate	Very limited
KANE	Moderate	Very limited
KANKAKEE	Somewhat excessive	Somewhat limited
KARNAK	Very limited	Very limited
KEGONSA	Somewhat excessive	Somewhat limited
KELLER	Limited	Very limited
KELTNER	Moderate	Very limited
KENDALL	Moderate	Very limited
KEOMAH	Limited	Very limited
KEOWNS	Very limited	Very limited
KIDDER	Somewhat excessive	Moderate
LAHOGUE	Moderate	Very limited
LAROSE	Somewhat excessive	Moderate
LACRESCENT	High	Limited
LAMOILLE	Moderate	Somewhat limited
LAMONT	Somewhat excessive	High
LANDES	Somewhat excessive	Somewhat limited
LAWNDALE	Moderate	Very limited
LAWSON	Moderate	Very limited
LENA	Very limited	Very limited
LENZBURG	Moderate	High
LETA	Very limited	Very limited
LISBON	Limited	Very limited
LITTLETON	Moderate	Very limited
LORAN	Limited	Very limited
LORENZO	Somewhat excessive	Moderate
LUCAS	Moderate	Somewhat limited
MAHALASVILLE	Very limited	Very limited
MARINE	Limited	Limited
MARISSA	Moderate	Very limited
MARKHAM	High	Limited
MARSEILLES	Moderate	Very limited
MARSHAN	Very limited	Very limited
MARTINSVILLE	Somewhat excessive	Moderate
MARTINTON	Limited	Very limited
MASSBACH	Moderate	Very limited
MAUMEE	Very limited	Very limited
MCGARY	Limited	Very limited

MCHENRY	Somewhat excessive	Moderate
MEDARY	Limited	Very limited
MEDWAY	Somewhat excessive	Very limited
METEA	Somewhat excessive	Moderate
MIAMI	Somewhat excessive	Moderate
MIAMIAN	High	Moderate
MIDDLETOWN	Somewhat excessive	Moderate
MILFORD	Very limited	Very limited
MILLBROOK	Moderate	Very limited
MILLSDALE	Limited	Very limited
MOKENA	Limited	Very limited
MONTGOMERY	Limited	Very limited
MONTMORENCI	High	Limited
MORLEY	High	Moderate
MOROCCO	Limited	Very limited
MORRISTOWN	Moderate	Moderate
MT.CARROLL	Somewhat excessive	Moderate
MUNDELEIN	Moderate	Very limited
MUREN	Somewhat excessive	Moderate
MUSCATINE	Moderate	Very limited
MUSKEGO	Very limited	Very limited
NACHUSA	Limited	Very limited
NAPPANEE	Limited	Very limited
NEWBERRY	Limited	Very limited
NEWGLARUS	Moderate	Very limited
NEWTON	Very limited	Very limited
NIOTA	Limited	Very limited
OAKVILLE	Somewhat excessive	High
OCONEE	Limited	Very limited
OCTAGON	Somewhat excessive	Moderate
ODELL	Limited	Limited
OGLE	Somewhat excessive	Somewhat limited
OKAW	Limited	Very limited
ONARGA	Somewhat excessive	Somewhat limited
ORIO	Very limited	Very limited
ORION	Limited	Very limited
ORTHENTS	Limited	Limited
OSHTEMO	Somewhat excessive	Moderate
PALMS	Very limited	Very limited
PALSGROVE	Moderate	Very limited
PAPINEAU	Limited	Limited
PARR	Somewhat excessive	Moderate
PATTON	Very limited	Very limited
PECATONICA	Somewhat excessive	Moderate
PELLA	Very limited	Very limited
PEOTONE	Very limited	Very limited
PETROLIA	Very limited	Very limited
PIASA	Limited	Very limited
PIOPOLIS	Very limited	Very limited
PLAINFIELD	Excessive	Excessive
PLANO	Somewhat excessive	Somewhat limited

PLATTVILLE	Moderate	Very limited
PORTBYRON	Somewhat excessive	Moderate
PRAIRIEVILLE	High	Very limited
PROCTOR	Somewhat excessive	Somewhat limited
RACOON	Very limited	Very limited
RADDLE	Somewhat excessive	Moderate
RADFORD	Limited	Very limited
RANTOUL	Limited	Very limited
RAPATEE	Limited	Very limited
RAUB	Limited	Limited
REDDICK	Very limited	Very limited
REESVILLE	Limited	Limited
RENSSELAER	Very limited	Very limited
RICHWOOD	Somewhat excessive	Somewhat limited
RIDGEVILLE	Moderate	Very limited
RIDOTT	Limited	Very limited
RINGWOOD	Somewhat excessive	Somewhat limited
RIPON	Moderate	Very limited
ROBY	Moderate	Somewhat limited
ROCKTON	Moderate	Very limited
RODMAN	Excessive	High
ROWE	Limited	Very limited
ROZETTA	Somewhat excessive	High
RUARK	Very limited	Very limited
RUSH	Somewhat excessive	Moderate
RUSHVILLE	Limited	Very limited
RUSSELL	Somewhat excessive	Moderate
RUTLAND	Limited	Very limited
SABINA	Limited	Very limited
SABLE	Very limited	Very limited
SARPY	Excessive	High
SAWMILL	Very limited	Very limited
SAYBROOK	Somewhat excessive	Limited
SAYLESVILLE	High	Limited
SAYLESVILLE	High	Limited
SCHAPVILLE	Moderate	Very limited
SCHULINE	Moderate	Somewhat limited
SCIOTOVILLE	Limited	Very limited
SEAFIELD	Moderate	Very limited
SEATON	Somewhat excessive	Moderate
SEBEWA	Very limited	Very limited
SELMA	Very limited	Very limited
SEXTON	Very limited	Very limited
SHADELAND	Limited	Very limited
SHARON	Somewhat excessive	Somewhat limited
SHOALS	Limited	Very limited
SHULLSBURG	Limited	Very limited
SIMONIN	High	Very limited
SLOAN	Very limited	Very limited
SOGN	Moderate	Somewhat limited
SPARTA	Excessive	Limited

SPINKS	Somewhat excessive	Somewhat limited
ST.CHARLES	Somewhat excessive	Moderate
ST.CLAIR	Moderate	Very limited
STARKS	Moderate	Very limited
STONELICK	Somewhat excessive	Somewhat limited
STOY	Limited	Very limited
STRAWN	Somewhat excessive	High
STREATOR	Very limited	Very limited
STRONGHURST	Moderate	Limited
SUNBURY	Limited	Very limited
SWANWICK	Limited	Limited
SWYGERT	Limited	Very limited
SYLVAN	Somewhat excessive	High
SYMERTON	High	Very limited
TAMA	Somewhat excessive	Somewhat limited
TAMALCO	Moderate	Very limited
TELL	Somewhat excessive	Somewhat limited
THEBES	Somewhat excessive	High
THETFORD	Limited	Very limited
THORP	Very limited	Very limited
TICE	Limited	Very limited
TITUS	Very limited	Very limited
TORONTO	Moderate	Very limited
TRAER	Very limited	Very limited
TROXEL	Somewhat excessive	Very limited
UNIONTOWN	High	Moderate
URBANLAND	Moderate	Somewhat limited
VALTON	Moderate	Somewhat limited
VANPETTEN	Somewhat excessive	Moderate
VARNA	High	Limited
VELMA	Somewhat excessive	Somewhat limited
VIGO	Limited	Very limited
VIRDEN	Very limited	Very limited
WAKELAND	Limited	Very limited
WALDRON	Very limited	Very limited
WARE	Somewhat excessive	Somewhat limited
WARSAW	Somewhat excessive	Somewhat limited
WASHTENAW	Very limited	Very limited
WATSEKA	Moderate	Very limited
WAUCONDA	Moderate	Very limited
WAUKEGAN	Somewhat excessive	Somewhat limited
WAUPECAN	Somewhat excessive	Somewhat limited
WEA	Somewhat excessive	Moderate
WEIR	Limited	Very limited
WELLSTON	Limited	Very limited
WENONA	High	Very limited
WESLEY	Limited	Very limited
WESTLAND	Very limited	Very limited
WESTVILLE	Somewhat excessive	Moderate
WHALAN	Moderate	Very limited
WHITAKER	Moderate	Very limited

WILL	Very limited	Very limited
WILLIAMSPORT	Limited	Very limited
WILLIAMSTOWN	High	Somewhat limited
WINGATE	High	Limited
WINNEBAGO	Somewhat excessive	Somewhat limited
WOODBINE	Moderate	Very limited
WORTHEN	Somewhat excessive	Very limited
WYNOOSE	Limited	Very limited
XENIA	High	Limited
ZANESVILLE	Limited	Limited
ZIPP	Very limited	Very limited
ZURICH	Somewhat excessive	Moderate
ZWINGLE	Limited	Very limited

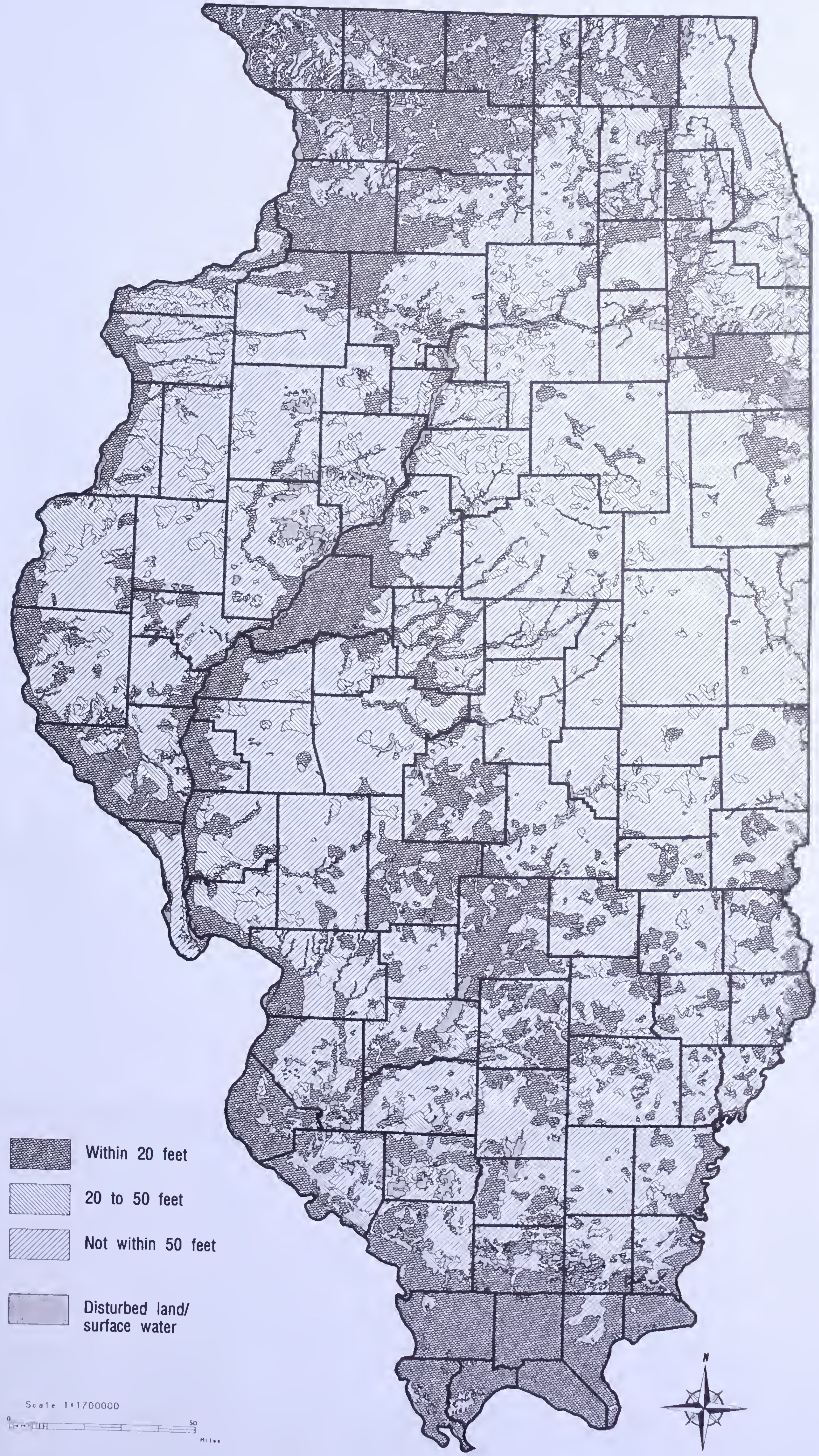

Plate 1 Depth to uppermost aquifer in Illinois.

Plate 2 Nitrate leaching classes of Illinois soils.

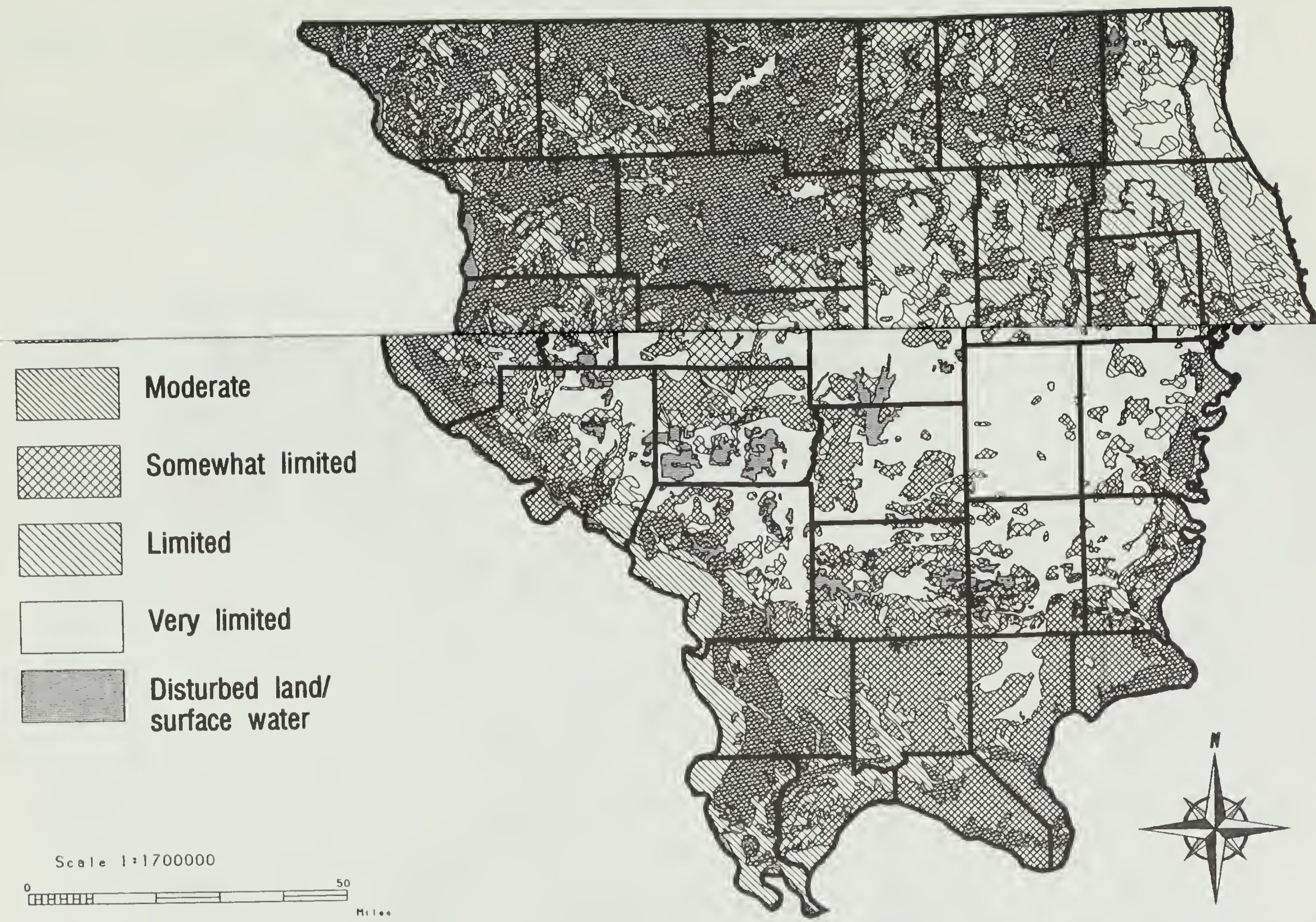

Plate 3 Aquifer sensitivity to contamination by nitrate leaching in Illinois.

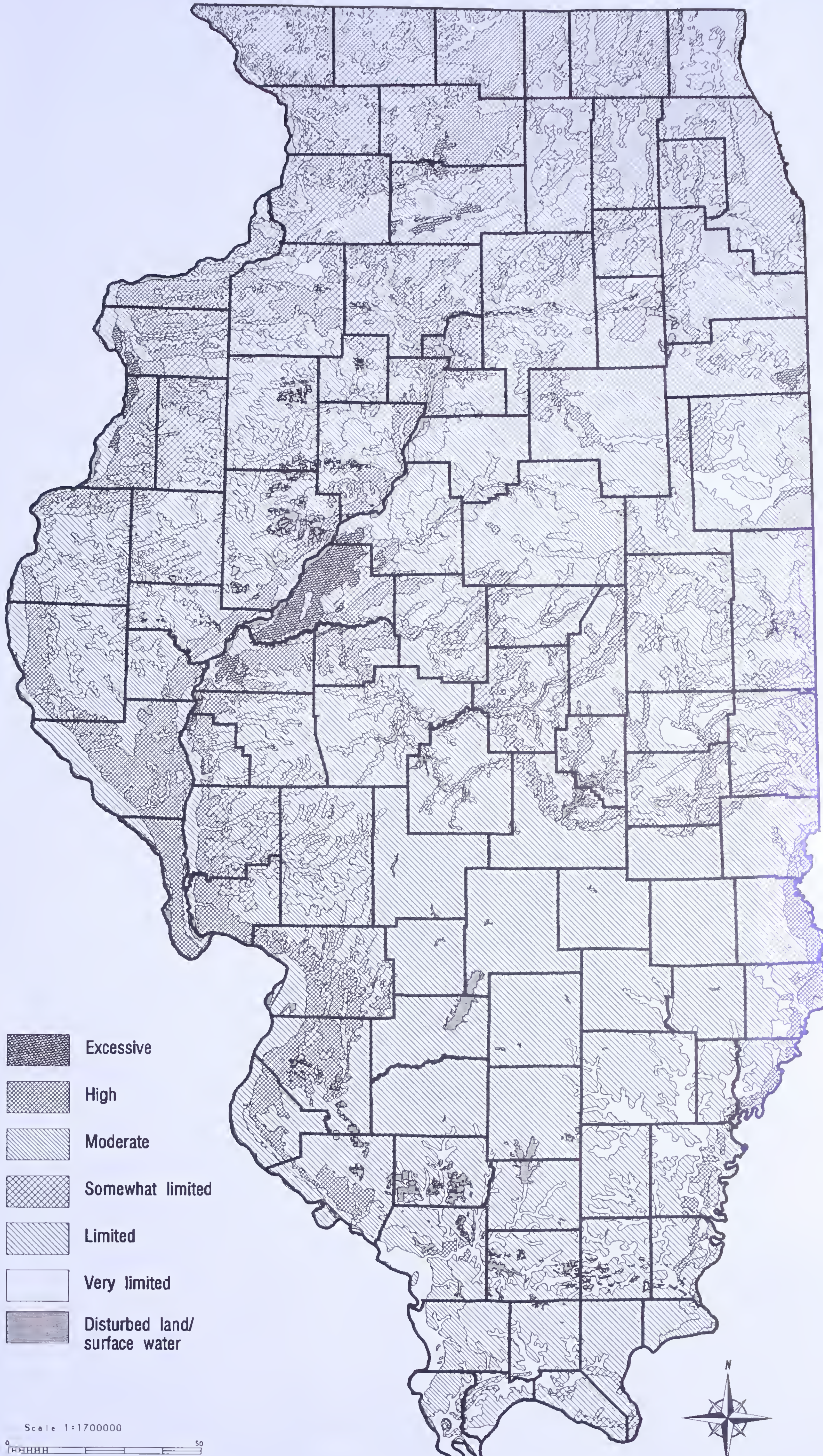

Plate 2 Nitrate leaching classes of Illinois soils.

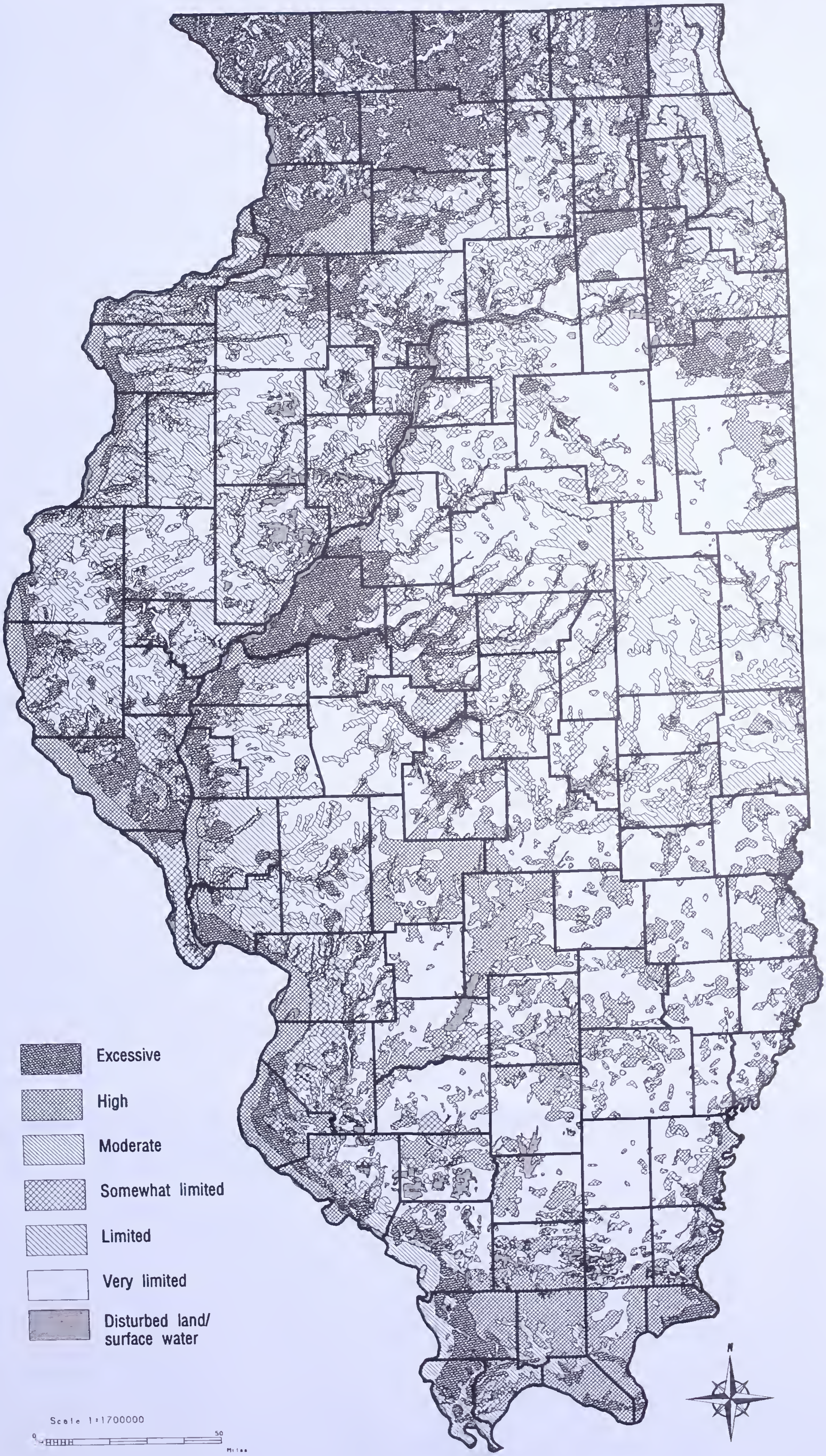

Plate 3 Aquifer sensitivity to contamination by nitrate leaching in Illinois.

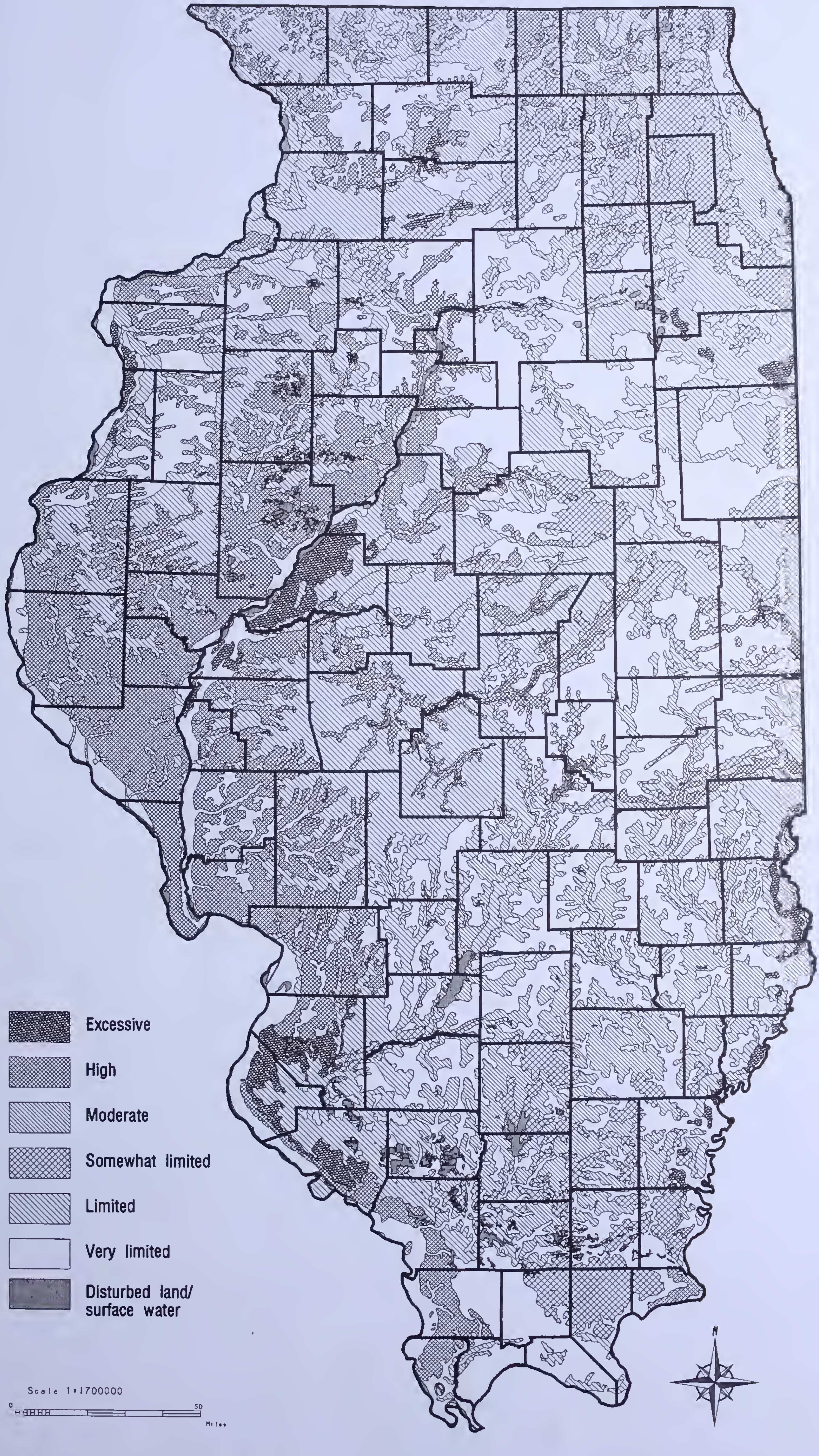

Plate 4 Pesticide leaching classes of Illinois soils.

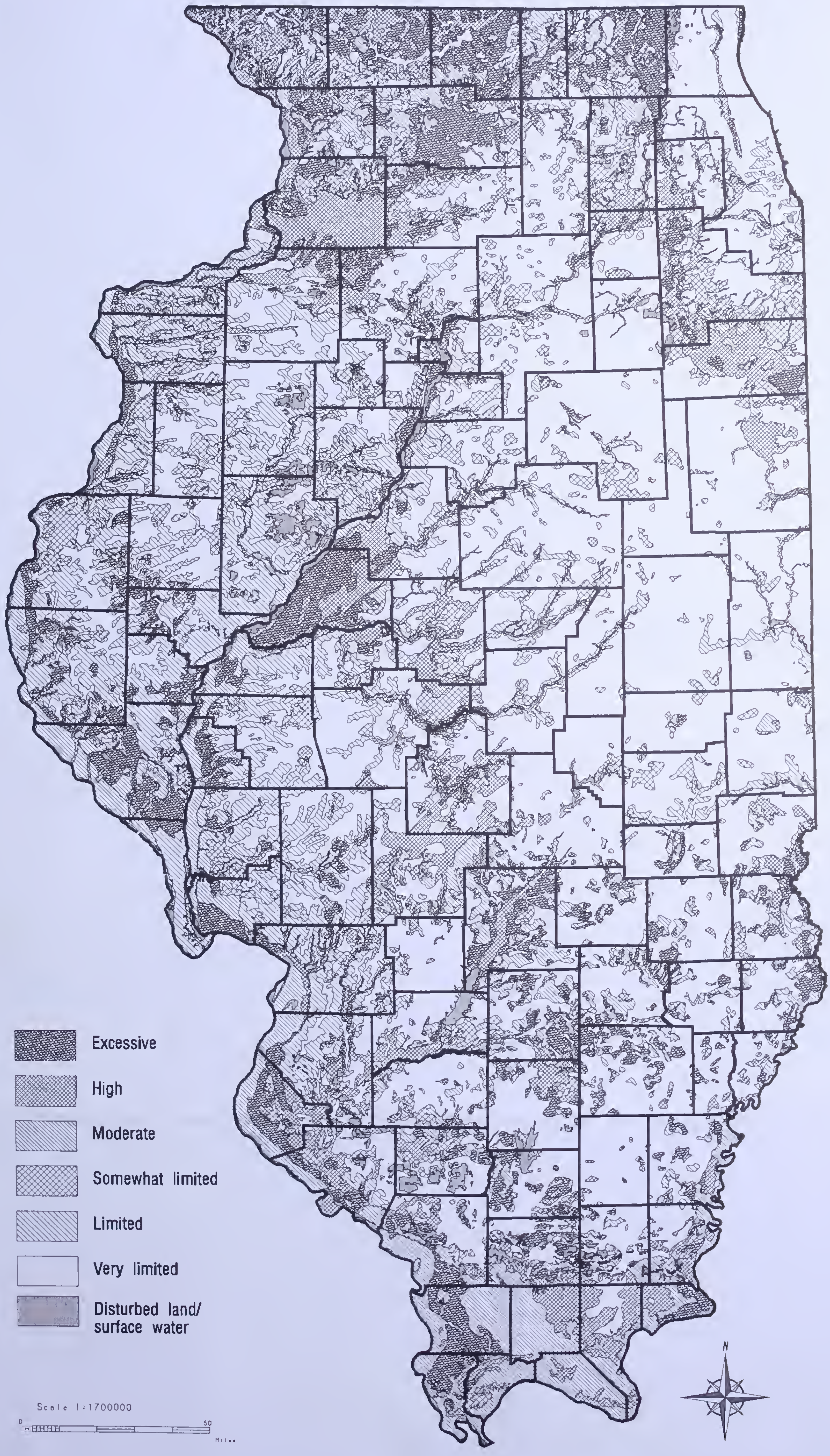

Plate 5 Aquifer sensitivity to contamination by pesticide leaching in Illinois.